GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

# PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. D-48-601 GTRI/~~GIT~~ DATE 1/26/83

Project Director: James M. Akridge School/~~Lab~~ Arch

Sponsor: Georgia Power Company
Atlanta, GA 30302

Type Agreement: P. O. K50200

Award Period: From 12/17/82 To ~~9/30/83~~ 12-31-83 (Performance) 10/31/83 (Reports)

Sponsor Amount: Total Estimated: $ ______ Funded: $ 35,240

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Investigation of Detached Earth Tempering as a Passive Cooling Technique for Georgia

## ADMINISTRATIVE DATA

OCA Contact John W. Burdette x4820

1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:
Buddy Luther
(404) 526-6526
Georgia Power Co.
333 Piedmont Avenue
Atlanta, GA 30302

Defense Priority Rating: NA

Military Security Classification: NA
(or) Company/Industrial Proprietary: NA

## RESTRICTIONS

See Attached ______ Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with ______

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EORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date April 25, 1984

roject No. D-48-601 School/~~Lab~~ Architecture

ncludes Subproject No.(s)

roject Director(s) James M. Akridge GTRI / ~~GIT~~

ponsor Georgia Power Co.

itle Investigation of Detached Earth Tampering as a Passive Cooling Technique for Georgia

ffective Completion Date: 12/31/83 (Performance) 1/31/84 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] ~~Classified Material Certificate~~
- [ ] Other

Continues Project No. Continued by Project No.

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Form OCA 60:1028

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
ARCHITECTURE PROGRAM
(404) 894-4885

Energy Research Department
Georgia Power Company
333 Piedmont Road
Atlanta, Georgia 30302

Attention: Mr. Bill Craig

Subject: Letter Progress Report No. 1 - "Investigation of Detached Earth Tempering"

Work since January has concentrated on getting the field and related control systems operating at maximum efficiency. It was decided early in January that the system was not leaking and that efficiency and reliability could be improved by adding ethylene glycol to the water in the system. This permitted the system to run all hours when the ground temperature was above the air temperature without our worrying about loss of power causing the pump to stop and the system freezing. We originally used a battery driven inverter to power the pump and worried anyway. Addition of the ethylene glycol may not have increased efficiency but it decreased worry. Since the total volume of the circulating system was approximately seventy gallons, the cost to get the freeze point of the circulating fluid below 15 F was relatively low.

The mild winter we have been having has not helped the field cool off. Because of the mild weather we added two 1/12 hp fans to the air-to-water heat exchanger. We don't feel these are normally needed, but the mild weather caused us to resort to forced convection to increase the transfer rate. The average field temperature is running about 54 F at the present time. This is higher than we had expected for a normal winter. The field is still charging whenever the outside temperature drops below the 54 F. Since energy is diffusing into the field from soil at depths greater than the field, we do not expect the average field temperature to decrease further. This diffusion does decrease the temperature of the soil beneath the field. Lower adjacent soil temperature is almost as useful as lower average field temperature as far as the detached tempering concept is concerned.

The data acquisition system has been performing very well. We initially monitored only 60 thermocouples because one of the data loggers was being used in another experiment. We are now monitoring over

100 sensors. This is probably a classic case of overkill since temperatures change so slowly throughout the field, but we feel that too many monitored temperatures is preferable to too few. We are in the process of reducing and plotting the data from the temperature sensors and will have data to report in my next report. All data taken thus far has been dumped to the IBM and is being "massaged" to remove extra information added by the data logger. Plotting routines will be used for selected sensors as soon as the data is in the proper form.

I have included four figures showing sensor locations within the field. Figures 1 and 2 show plan views of the field at the 4' and 8' levels. Figures 3 and 4 give cross section N-S and E-W.

We are presently checking out the building load programmer so that the building load can be simulated as soon as a cooling load is needed in this area. As you are aware, it is important that stored energy be used as soon as possible. Since no insulation is perfect, cooling capacity will be lost if this capacity is not used when it is needed. Failure of the load programmer was one of the reasons the single level field failed to perform as well as expected. We expect to not be faced with that problem this time.

Sincerely,

James M. Akridge, P.E.
Associate Professor of Architecture

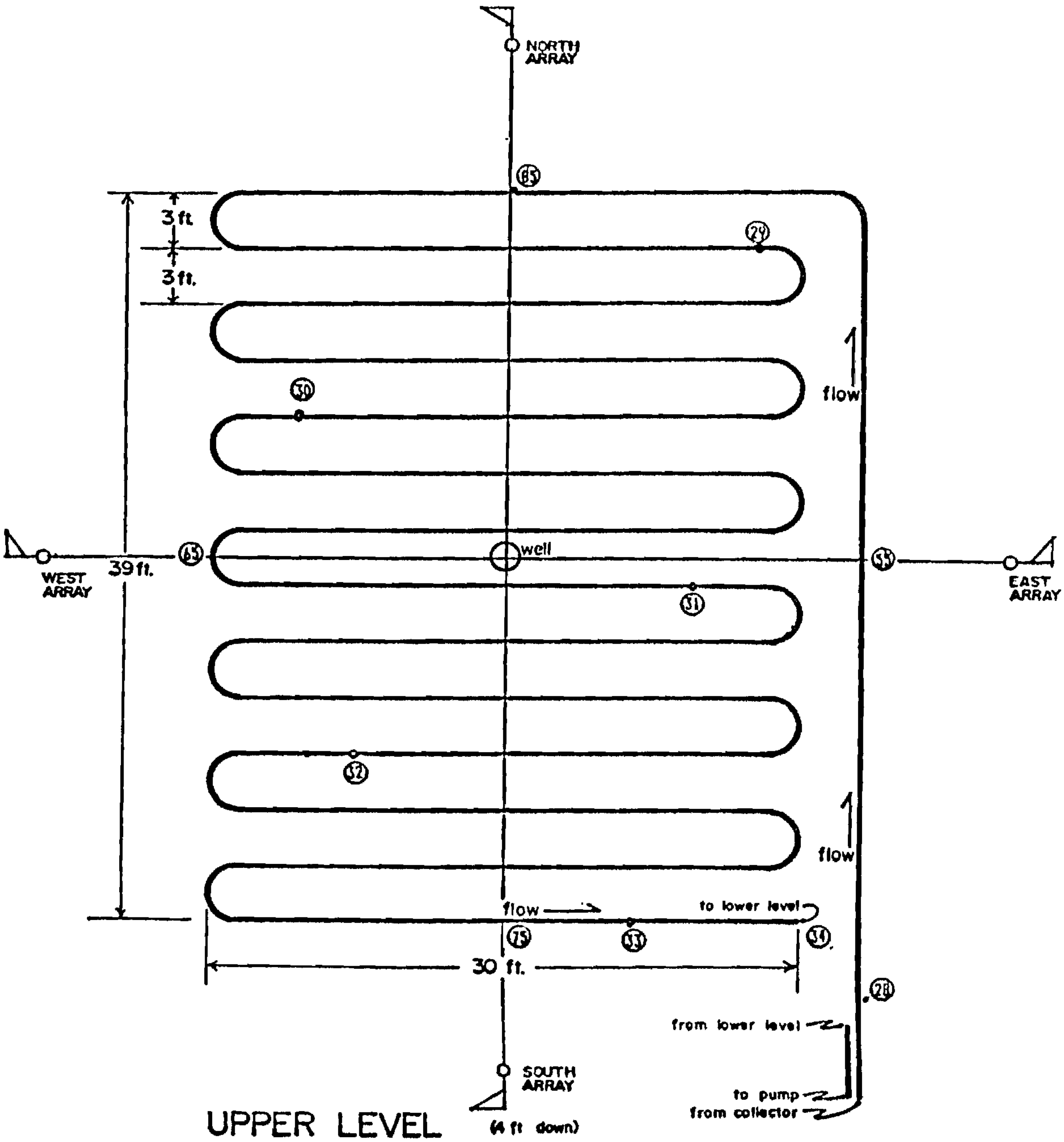


Figure 1 Plan View of Double Level Vield - 4' Level

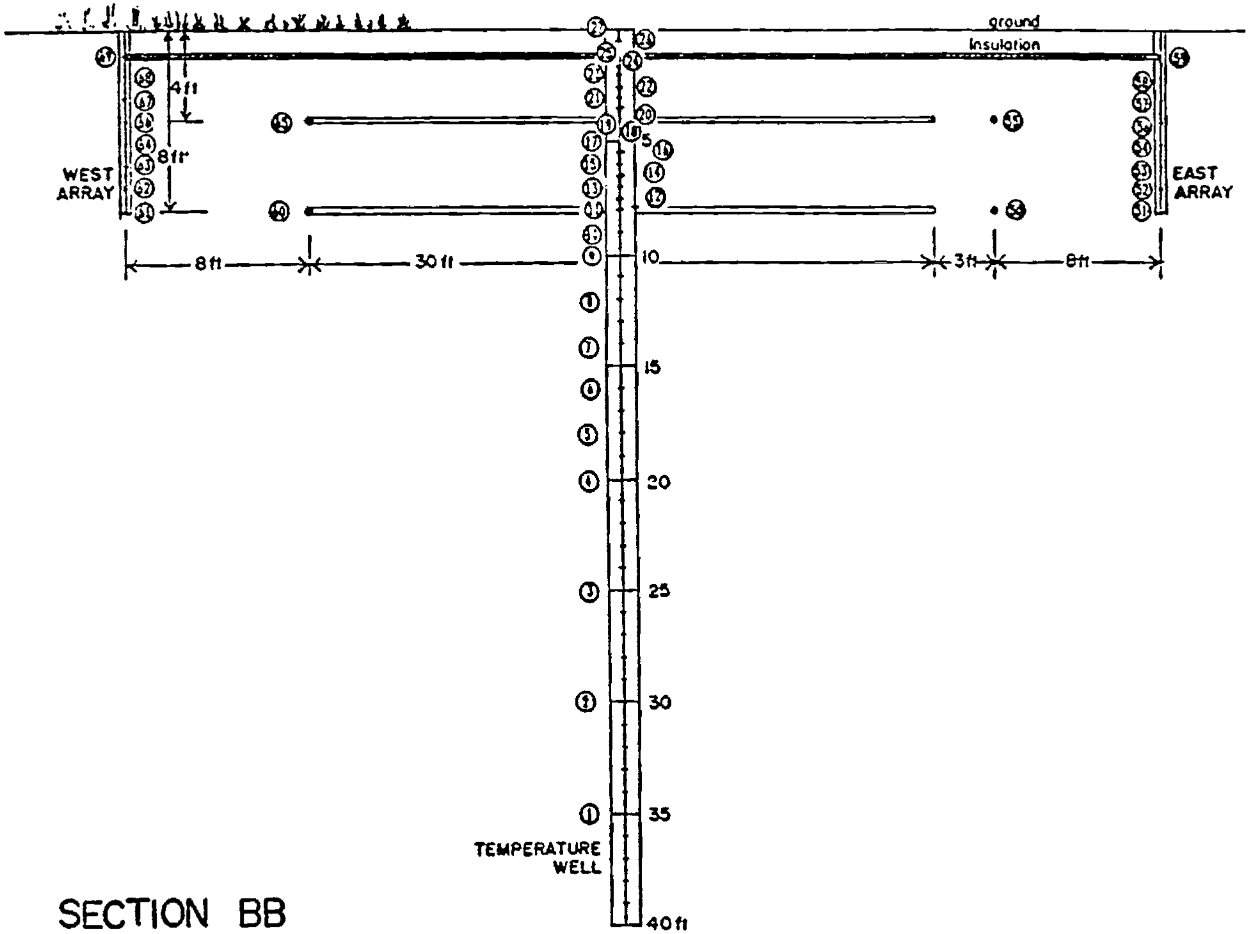


Figure 3 Section Through Double Level Field Looking South

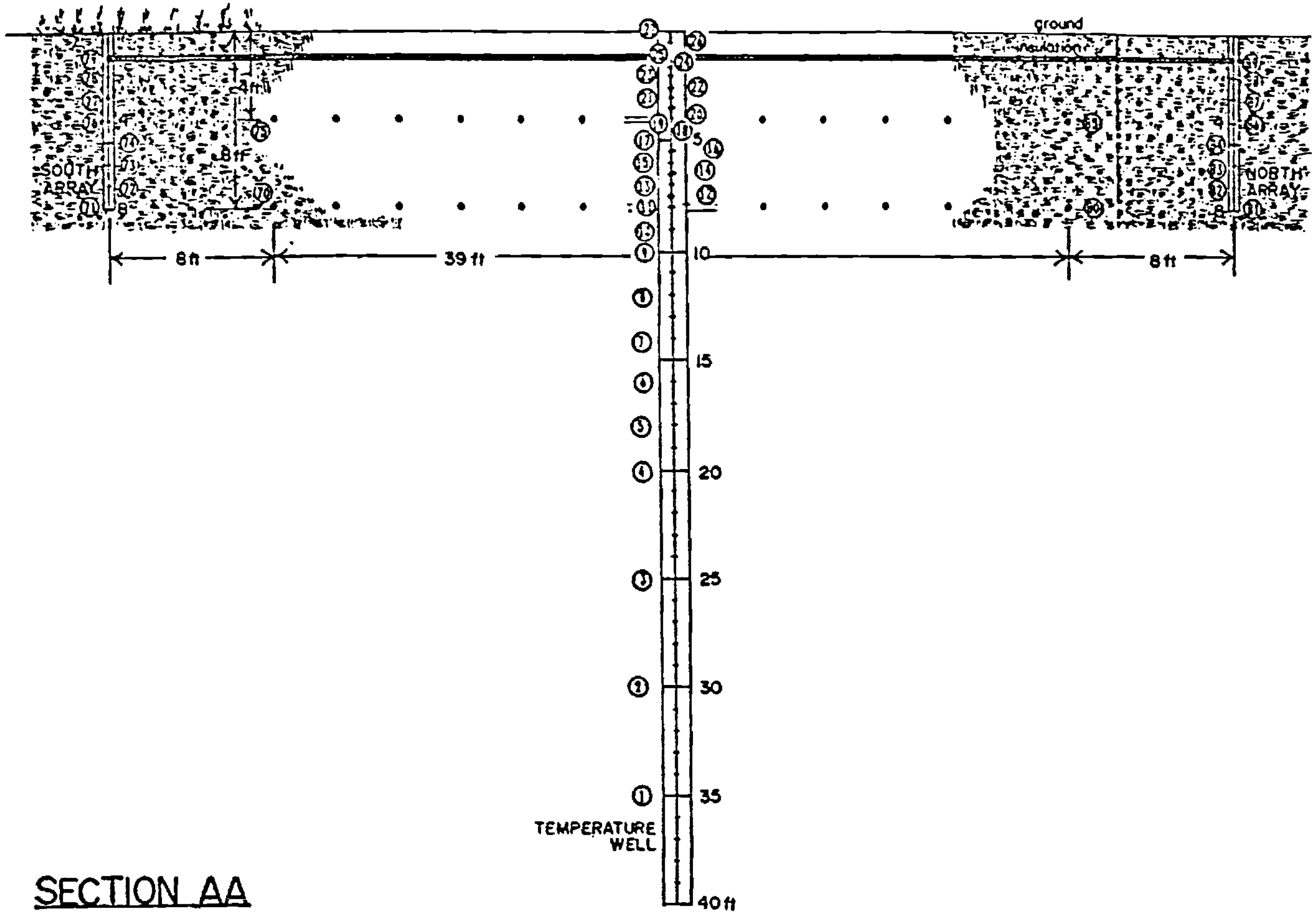


Figure 4  Section Through Double Level Field Looking East

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Letter Progress Report No. 2

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
ARCHITECTURE PROGRAM
(404) 894-4885

26 April 1983

Georgia Office of Energy Resources
270 Washington Street
Atlanta, Georgia 30334

Attention: Ms. Robin Meyer

Subject: Letter Progress Report No. 3 - "Evaluation of a Duty Cycling Device for Air Conditioners"

Dear Ms. Meyer:

I have talked with Jimmy Hill of Georgia Power and he has agreed to find several houses from which we can choose the house for evaluation of the load control device. We have ordered the thermocouple wire we will need to measure the temperatures and are constructing the aspirated wet-bulb thermocouple probes.

As soon as Jimmy finds the houses, I'll give you a call and we will review the houses he has found.

We also need to decide next month on the load control device you wish tested. As you know, there is a tremendous difference between the different load control devices on the market. Some like "Savit" are just simple timers while others are super-sophisticated brains which help the thermostat. One would expect the simple timers to be of little or no benefit while the others may be of minor benefit, depending on the quality of the thermostat.

Please let me know if you have any questions or advice.

Sincerely,

James M. Akridge, P.E.
Associate Professor of Architecture

D-4X-ln// |

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
RESEARCH PROGRAM
(404) 894-3476

1 June 1983

Georgia Office of Energy Resources
270 Washington Street
Atlanta, Georgia 30334

Attention: Ms. Robin Meyer

Subject: Letter Progress Report No. 4 - "Evaluation of a Duty Cycling Device for Air Conditioners"

Dear Ms. Meyer:

I had originally planned to start the tests on the duty cyclers sometime in June, but the very mild weather we have been having suggests that we wait until July. I think it is important that the devices be tested when the weather demands that the air-conditioner be used extensively. Bill Craig called to say that Jimmy would like a meeting on 6 June to decide about the four houses needed for the tests.

I believe that we should test "Savit" on two houses. One house should have the air-conditioner properly sized, as it would be on a "Good Cents' house. The second house should have the air-conditioner over-sized, as it might be with most other houses. If "Savit" is used on two houses, we need to select the other two devices for evaluation. I think the remaining houses should be houses with properly sized air-conditioners. I would like to have Georgia Power involved in the selection of the other two devices, but would also like your opinion. I now have data on five devices which are briefly described below:

1. SAVIT - This device is a simple electrically driven mechanical timer which can be adjusted to turn the air-conditioner off an adjustable percentage of the time. This one probably should be tested.

2. ENERUPT - This is similar to the Savit. I would expect the two devices to have similar performance.

3. THERMOSTAT REGULATOR - This device is the one sold by Davidsons. The literature they sent to me doesn't discuss the operation of the device at all. Davidsons tells me that the device is made by The House of Fans, but all of their numbers have been disconnected.

4. THE ENERGY COMPUTER - This device is sold by Electro Tech Manufacturers of Norcross. It appears to be a super sophisticated addition to the thermostat. It cuts back on the time the compressor

runs until the thermostat is not satisfied. When the thermostat is not satisfied the device increases the run time. It would appear they could have incorporated the device into the thermostat rather than have a separate device. Electro Tech is anxious to have the device tested.

5. THE ENERGY SAVER - This device is made by a division of Aviation Electronics, Inc. of Chamblee. It measures the temperature of the air in the air return duct and tries to reduce the run time of the compressor yet still meet the thermostat setting. Although they have taken a different approach than the Energy Computer, it would appear they should also incorporate their device in a thermostat. These people are also very interested in their device being tested.

I called National Energy Associates about their device. The can't makeup their mind whether they want the device tested or even send literature. If I can get data on the device I'll be able to decide whether they have anything different. Their secrecy about the device is not encouraging.

I talked with Don Sabin about additional devices. He said that the five devices I presently have data on are probably representative of the remaining devices.

If you have questions please give me a call.

Sincerely,

James M. Akridge, P.E.
Associate Professor of Architecture
College of Architecture

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
ARCHITECTURE PROGRAM
(404) 894-4885

5 July 1983

Georgia Office of Energy Resources
270 Washington Street
Atlanta, Georgia 30334

Attention: Ms. Robin Meyer

Subject: Letter Progress Report No. 5 - "Evaluation of a Duty Cycling Device for Air Conditioners"

Dear Ms. Meyer:

Georgia Power has selected four houses for use in evaluation of the duty cycling devices. Three of the houses are "townhouses" and are located in the same complex. These three are "Good Cents" homes with their heat-pump properly selected. These are located in Dekalb County near Dunwoody. The fourth home is located in Roswell and has an oversized heat-pump. The four homes, their addresses and phone numbers are listed below:

1. Richard P. Norris
   8877 Longbeach Circle
   Atlanta, Georgia 30338
   587-1356 (home)
   588-7502 (work)
   394-9813 (work)

2. David E. Warren
   8880 Long Beach Circle
   587-1351 (home)
   252-2775 (work)

3. Edgar Lindgren
   8870 Long Beach Circle
   992-1533 (home)
   952-2775 (work)

4. David J. Parton
   256 Barrington Drive
   Roswell, Georgia 30075
   998-7562

I will contact each of the owners and make arrangements to have the duty cycler installed. We will also install the instrumentation at the same time. I have made arrangements to have Georgia Power install a recording power meter on each of the houses.

We have checked out our instrumentation as much as possible without having access to the actual device being tested. We feel that we can take sufficient data to make a meaningful evaluation. Although we are planning on a two week test period, experimental research programs have a way of not proceeding smoothly. We will take data until we are sure we have the data we need.

I will give you a phone call before we begin installation. If you have any questions are wish to talk about the program, please give me a call.

Sincerely,

James M. Akridge, P.E.
Associate Professor of Architecture

FINAL REPORT

# INVESTIGATION OF DETACHED EARTH TEMPERING

By

James M. Akridge

Prepared for

THE GEORGIA POWER COMPANY
333 Piedmont Road
Atlanta, Georgia 30302

January 1984

**GEORGIA INSTITUTE OF TECHNOLOGY**
**A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA**
**SCHOOL OF ARCHITECTURE**
**ATLANTA, GEORGIA 30332**

1984

# INVESTIGATION OF DETACHED EARTH TEMPERING

By
James M. Akridge

Prepared for

THE GEORGIA POWER COMPANY
333 PIEDMONT ROAD
ATLANTA, GEORGIA 30302

Prepared by

The College of Architecture
Atlanta, Georgia 30332

30 January 1984

# EXECUTIVE SUMMARY

Approximately 1000 ft. of 1.25" nominal diameter polyethylene 2306 tubing was installed in a detached earth tempering experiment at the College of Architecture, Georgia Institute of Technology. Half of the tubing was buried in a serpentine configuration at a depth of 8' and connected in series with the remaining half located at a depth of 4'. The field was insulated from the ground surface with 2" of extruded styrofoam insulation located 1' below the ground surface.

This detached field was cooled during the winter months by circulating a mixture of water and ethylene glycol through an above ground air-to-water heat exchanger and then through the pipe buried in the field. Average field temperatures of 55 F were reached at the end of March.

This cooling field was used to carry a simulated load for a 1500 sq.ft. house for the months May through September. The cooling loads simulated were developed from measured sensible cooling loads for a Georgia Power research house located in Columbus, Georgia. These measured loads were programmed into a computer controlled electric resistance heater through which water from the cooling field was circulated.

The field carried all of the May through August load completely passively, i.e, no assistance from a mechanical system, other than a 75 watt water circulating pump, was required. The overall system COP for these four months varied from 6.4 to 10.9. The temperature of the water coming from the field reached 74 F at the end of August, requiring the September load to be carried by a water-to-water heat pump which dumped the load to the cooling field. The temperature of the water coming from the field was 84 F at the end of September. Due to the use of a water-to-water heat pump with a very low COP the overall system COP for September was 1.56. COP for the season was 3.4.

Although the COP's for the first four months were fairly high, they were much lower than had been anticipated. The reason for the lower COP resulted from not having optimized the water circulating pump for the particular application. The primary objective of the program was to investigate the seasonal storage concept. It became painfully obvious that one must pay careful attention to the power consumed by circulating pumps if one wishes to maximize system efficiency.

The program showed that the detached earth tempering concept is technically feasible and that system efficiencies higher than any other cooling method can be realistically expected, though the success of the detached earth tempering concept is highly dependent upon the care one exercises in implementing the concept.

# INVESTIGATION OF DETACHED EARTH TEMPERING

## INTRODUCTION

### BACKGROUND

As energy resources become more scarce and costs continue to rise, it has become imperative that all segments of American society undertake significant measures to reduce energy consumption. Approximately thirty-five percent of the energy consumed in the United States is used to heat and cool buildings. Significant reductions in energy consumption are possible through changes in the way buildings are operated (energy management). Further reductions are possible through the use of better and more efficient mechanical systems, and through the use of active solar heating and cooling systems, although the latter is questionable from an economic standpoint at this time.

It is obvious that the greatest potential for energy reduction lies in the proper design of buildings. Passive architecture, as it is popularly called, is not a new innovation. Before the advent of efficient mechanical systems and readily available fuels, thermally passive architecture was the primary method for maintaining comfort, other than through the use of clothing and localized fires.

With the advent of cheap energy and mechanical systems capable of completely controlling an environment, designers relied less and less on the building itself to control its environment. This has led to the design of buildings over the last forty years which are less efficient each year, i.e., use more energy per ft.2, than the buildings designed the previous year.

As fuel costs began to rise in recent years several designers began to design passively heated buildings. This concept of using the building itself as a solar collector has received considerable attention and can be accomplished through proper design in most sections of the United States. Many architects and designers have learned how to incorporate passive heating features into residential, commercial and industrial building. Researchers like Balcolm, Mazria, TEA, and many others have developed design guidelines for passively heated buildings.

Although many of the principles useful in the design of passively heated buildings are also applicable to passively cooled buildings, passive cooling has proven to be much more difficult to accomplish effectively. This is particularly true in hot-humid climates. In hot-dry climates where nighttime temperatures are relatively low and/or atmospheric moisture content is low, diurnal cooling, evaporative cooling and radiation to the sky have proven to be effective methods for cooling buildings.

Unfortunately, much of the United States having high cooling loads lies in what is popularly called a hot-humid region. Direct evaporative cooling will not provide an increase in comfort during much of the cooling season due to relative humidities which are already higher than desirable. Radiation to clear night skies is also much less effective due to moisture in the air acting as an infrared trap. Diurnal cooling, i.e., moderating the day and night temperatures within a space through proper use of mass and insulation, is not very effective because the daily temperature swings are relatively low and latent loads are a significant percentage of the total cooling load.

## LITERATURE SEARCH

An initial task of an earlier cooling investigation, which provided the background for this program, was to thoroughly search the literature to determine whether cooling techniques have been used which are effective in reducing cooling loads in hot-humid regions. The literature search did not yield any passive cooling techniques showing promise for use by the majority of the building industry. Many of the more promising techniques are the obvious ones, such as the use of shading, light colored roofs and walls, insulation, and water sprayed roofs. Most of these were investigated thirty years ago in Israel, South Africa, and the United States, when fuel was cheap and mechanical systems were much more convenient and effective, and have not been pursued or developed further until recently.

Many earth cooling tube concepts show promise but possess problems either ignored or not recognized. Most proponents of these systems have ignored the problem of air discharged into a living space at 70-75o F in a saturated state. Even when mixed with dry indoor air, comfort is not likely to result. Several investigators suggest that computer simulations show that ground conductivity is not really important and thermal saturation is not likely to occur. Experience with ground loop heat pumps 20-30 years ago indicates ground saturation may be a problem if the ground loop is not carefully sized for the load it must carry.

In summary, no purely passive cooling techniques exist which show promise of being effective in hot-humid climates. All approaches to passive design, whether heating or cooling, must start with the premise that the structure is designed to minimize loads due to external conditions. This means that insulation in walls and roof has been optimized, that the building has been properly oriented to take advantage of the sun and prevailing winds, that the windows have been properly sized and located, that proper shading has been provided for the windows, and that optimum use has been made of local terrain and trees. Passive cooling design also requires the use of light colored roofs and walls where possible. While the above guidelines might be considered passive cooling concepts because they greatly reduce cooling loads, they are more appropriately called load minimization techniques. They are effective at reducing thermal loads no matter what they are called.

## EARTH TEMPERING

The earlier study did demonstrate the potential of earth tempering as passive cooling technique for hot-humid climates. Earth tempering is the term presently used for structures which are buried, or semi-buried and use the ground both as insulation and as a thermal mass to moderate temperature differentials across building elements. When properly designed, these buildings usually perform quite well, unless the building has a high internal heat gain such the case with industrial or large commercial buildings.

The success of earth tempered buildings is usually highly dependent upon the depth at which the building is placed, as well as the quantity, size, and the orientation of openings to the surface. At most latitudes in the United States, it is desirable to have some glazing facing south either directly or through an atrium.

The most difficult problem facing earth tempered buildings in a hot-humid climate is the same problem faced by all passive cooling techniques in this climate: humidity control. One does not want earth tempered buildings to carry latent loads because it manifests itself as water condensation on walls, floors, and ceilings. This is undesirable from comfort, health and aesthetic standpoints. Latent load control is discussed later in the report.

Unlike most passive techniques, earth tempering in hot-humid climates has been held back by a technical problem. Until recently, it was not possible to control infiltration sufficiently well to make earth tempering practical in hot-humid climates. The importance of infiltration or ventilation control in hot-humid climates becomes very apparent when one looks at the latent and sensible loads of a building as a function of the ventilation (infiltration) rates while keeping the ventilation air temperature constant. If the relative humidity of the air is now varied, one finds the only difference in the thermal load on buildings in arid and humid climates is due to the latent loads caused by ventilation (infiltration). Obviously, if infiltration can be greatly reduced and carefully controlled, a building in a humid climate will perform nearly the same as one in an arid climate.

Although the earlier study showed heating and cooling potential for earth tempering, it also identified serious architectural and market constraints on conventional earth tempered (underground) buildings. The study also showed that many of the thermal advantages of underground construction may be realized above ground through the use of a concept we have chosen to call "Detached Earth Tempering" (DET). If architectural constraints prevent taking the building underground, the Detached Earth Tempering Concept attempts to bring the thermal advantages of underground structures to above grade buildings.

BASIC CONCEPT

The basic concept behind Detached Earth Tempering is to bury coils in the earth through which water or other similar heat transfer fluids can circulate. The fluid having been cooled by earth contact can then be circulated through building elements such as the floor, ceiling or walls. If the walls are well insulated and the insulation is located on the outside of the structure, one will have a cool wall structure similar to that of an underground structure. If infiltration is controlled through the use of good seals, vapor barriers and air locks at the doors and if ventilation is accomplished through the use of an enthalpy exchanger, the building will perform similar to an underground structure in an arid climate.

Initial computer studies showed that ground temperatures at depths of 4-12 feet are much too high in late summer to provide appreciable cooling. These computer studies were checked with ground temperature measurements in two 40 ft wells drilled for this purpose. These measurements verified the accuracy of the equations used to predict the ground temperatures for areas well shaded. They also showed that areas with little ground cover can reach considerably higher temperatures.

Because high surface temperatures result in high temperatures at greater depths, one can minimize this effect by separating the surface from the soil at lower depths with insulation. Insulation of the soil from the surface also greatly reduces the rate at which energy can be lost to the ambient air during the winter months. This then requires that the soil beneath the insulation be thermally coupled to the above surface environment during the winter months if one is to have the low soil temperatures desired during the summer months.

BACKGROUND

Georgia Tech installed an experimental single level field with 700 feet of 1.5 inch low density polyethylene pipe buried at a depth of 4 feet with 3 feet of dirt directly above, followed by 2 inches of extruded polystyrene insulation. The insulation was covered with 1 foot of dirt and a good sod cover. Figure 1 shows a section of the Georgia Tech single level experimental field. Ideally the field would be placed beneath a house to minimize undesirable ambient loads. Since it could not be installed beneath a house, great care was exercised in providing a good sod cover to minimize radiant gains at the soil surface.

The insulated field was cooled during the winter months by circulating water through an above ground air-to-water heat exchanger and then through the buried coil. A differential thermostat turned on a small (1/15 hp) pump when the field was warmer than the ambient air.

Tests on the experimental single level field showed that despite repeated problems with instrumentation and equipment which seriously decreased the performance of the field, it was able to provide a significant percentage of the early summer cooling load completely passively.

These tests suffered from numerous leaks in the low density polyethylene tubing used to couple the detached field to the surface. The tests showed that considerably better reliability could be obtained if the low density polyethylene was changed to a medium density polyethylene pipe used by the natural gas industry for underground gas lines. The tests also showed that leaks could be significantly reduced if a sand bed was established around the pipe and large rocks kept out of the field backfill.

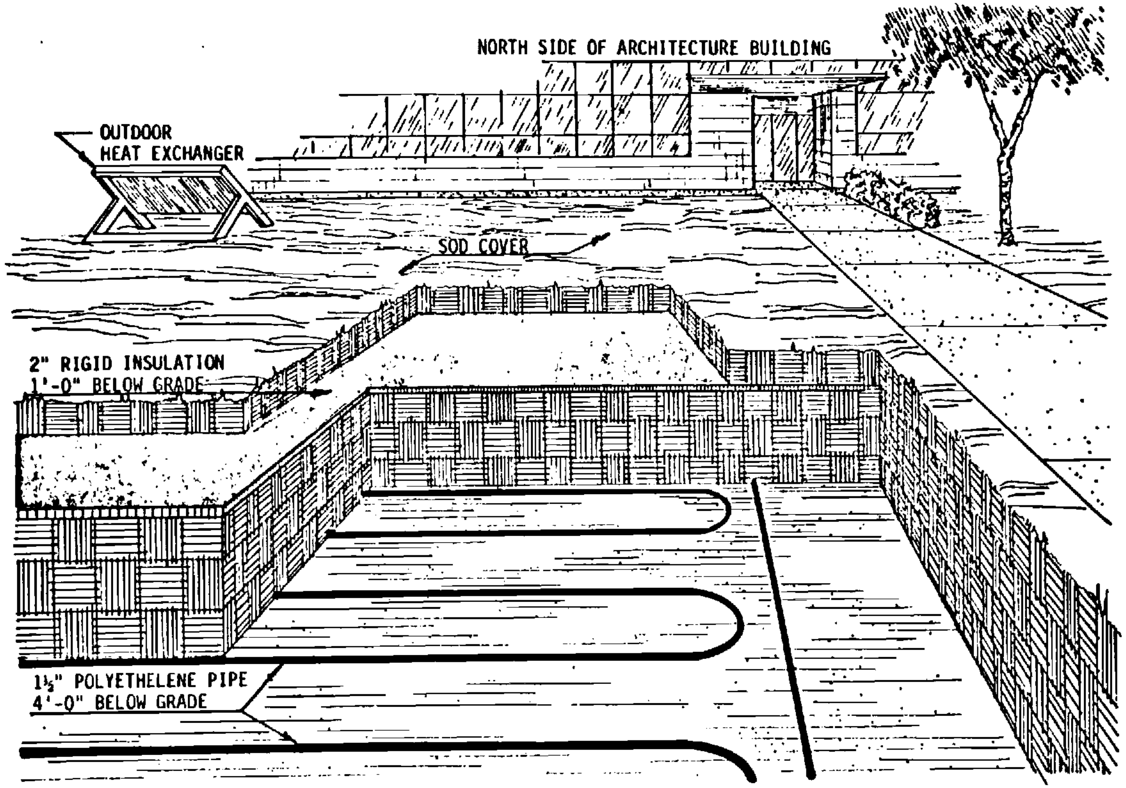


Figure 1. Single Level Detached Earth Cooling Field

Computer studies associated with these tests showed that significant improvements in performance and reduction in installion costs could be realized by going to a double level field with a reduced plan area.

The success of seasonal storage of cooling potential is highly dependent upon how one couples this cooling capacity to the occupants. Due to low grade cooling potential in the field, temperature differences are relatively small, conventional cool air systems will not perform satisfactorily. Cooling through the use of building elements such as walls, floors or ceilings appears to offer the most potential, because these elements provide large heat exchange surfaces in direct radiant contact with building occupants.

This brief description of the Detached Earth Tempering concept given here is meant to be only an introduction to the basic concept as first proposed. This report provides operation data for an experimental system evaluated at the Georgia Tech College of Architecture. Obviously, many changes, improvements, and refinements should result from data developed in these tests.

## DOUBLE LEVEL FIELD

As briefly discussed above the computer simulations conducted while evaluating the performance of the single level field showed that a significant increase in performance could be realized through the utilization of a double level field. The simulations also showed a significant increase in potential if the double level field is located beneath a house.

Delays in approval for installation of the double level field prevented replacing the field in early December 1981 as planned. Complete approval was not obtained until it was too late to get meaningful data during the winter of 1982. Unusually wet and cold weather prevented replacement of the field until early May 1982.

Considerable effort was directed toward determining whether others might encounter leakage problems with the DET concept similar to those experienced with the single level field. Extensive conversation with Georgia Power personnel regarding installation procedures for their underground power cables led us to believe that the great quantities of both curbstone and fieldstone left from an old road which had previously run through the site provided an unusually harsh environment for the single level field. Georgia Power only cautions their installation personnel to not allow rocks to be put back over the cables for the first foot.

Similar talks with the Atlanta Gas Light Company about their installation procedures for plastic underground gas lines indicated slightly greater care. Plastic gas line is made from a special formula medium density polyethylene as opposed to the low density commercial grade polyethylene used in the single level field. The gas pipe has a wall thickness of .150 in. rather than the .108 in. wall thickness of used in the original field. Fortunately, the 2306 gas pipe is readily available and is only slightly more expensive than the general purpose polyethylene pipe used in the original field. Plastic gas lines are also backfilled with screened soil for the first foot before excavated soil is replaced.

Approximately 1000 ft. of 1.25 in. nominal inside diameter 2306 polyethylene gas pipe was used in the new double level field. The 1.25 in. nominal diameter pipe was used because it is more readily available in the Atlanta area. The field was excavated to a depth of 8.5 ft., and backfilled with 6 in. of screened general purpose sand before the lower pipe level was laid. Use of the 1.25 in. nominal inside diameter pipe permitted us to install the pipe on 3 ft. centers rather than the 4 ft. centers used with the 1.5 in. pipe. Once the lower coils were in place they were covered with an additional 6 in. of screened general purpose sand before the hole was backfilled with 3 ft. of soil removed from the hole. Extreme care was taken to remove all rocks larger than 1 in. from the soil returned to the hole. Another 6 in. of screened general purpose sand was added before the top coil was laid. Once the top coil was in place a final 6 in. of screened sand was added as a cover before the hole was filled to 1 ft. below grade. Again, extreme care was exercised to remove rocks from the backfill. The field was insulated with 2 in. of Dow SM extruded polystyrene insulation 1 ft. below grade and covered with a 6 mil plastic vapor barrier to prevent rain movement through the field. Finally, the last foot of soil was added, the site graded and seeded with bermuda grass seed.

The computer simulations showed it was desirable to minimize plan area, i.e., reduce the area through which the field could gain energy from the surface. The double level field permits a considerably smaller plan area while maintaining large soil volume and pipe contact area. The pipe arrays in the double level field are both within an area of 30'x40' with the lower coil 8 ft. below grade and the top coil 4 ft. below grade. The insulation was extended 8 ft. beyond the edge of the coils in all directions. Figure 2 shows an exploded view of the new field, while Figure 3 shows a cross section of the field as it was installed.

The pipe comes from the building, goes through a 18 sq. ft. air-water heat exchanger directly into the ground to the 8 ft. level, and runs to the far end of the field where it serpentines back toward the building until 500 ft. has been run. It then rises to the 4 ft. level where it runs to the far end of the field and serpentines back toward the building until approximately 500 ft. has been run. It then rises to the surface and runs directly back into the building where the pumps and flow meters are located. With this arrangement, the surface area previously insulated was reduced by 40%, thus reducing one of the more costly items in the field. With a smaller plan area, less energy is lost to the surface. The plan area of the double level field is sufficiently small to fit under most reasonably sized houses.

## INSTRUMENTATION

The data acquisition system was initially installed to monitor 120 temperatures every four hours. This is a classic case of overkill since soil temperatures change so slowly. While too much data increases

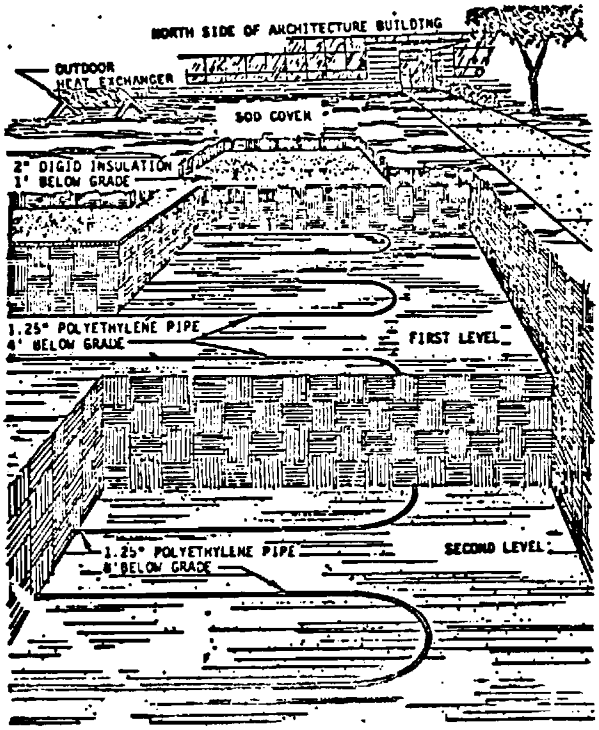


Figure 2. Double Level Earth Cooling Field

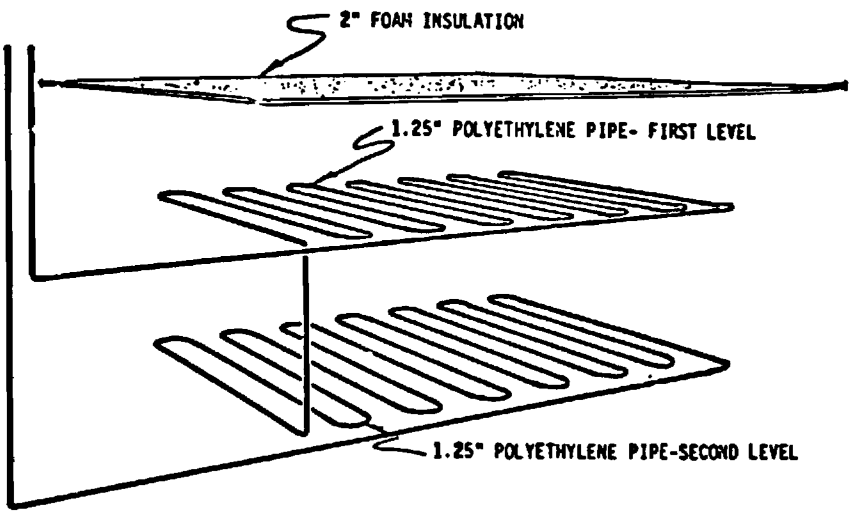


Figure 3. Exploded View of Double Level Cooling Field

reliability it also significantly increases the time required for data reduction. The number of points taken is not the problem, but the frequency of sampling is. Soil temperatures change so slowly that a sampling rate of twice a week would have been more than sufficient for this study.

Figure 4 shows the instrumentation layout within the field. Figures 5 and 6 show plan views of the field at the 4' and 8' depths. Figures 7 and 8 give cross sections looking east and south through the field.

## COOLING PERFORMANCE EVALUATION

Since a radiatively cooled house was not available for evaluation of the field performance, this evaluation was divided into two separate parts so that the effects of each could be evaluated. A load simulator was used to measure and evaluate the performance of the field and determine how well energy could be stored and extracted from the field.

The building load simulator consisted of a 20478 Btu/hr (6kw) electrical circulation heater whose power output could be controlled through a programmable load controller. Figure 9 is a schematic of the equipment used to simulate the thermal load on a house.

Actual measured electrical consumption of a Georgia Power "Good Cents" house located in Columbus, Georgia, was converted to hourly sensible cooling loads for each of the cooling months using the seasonal EER given by the manufacturer of the home's air conditioner. The load profile for the Georgia Power Answer house in Columbus, Georgia was used an example of a modestly sized house with low to medium load profile. Table I shows the monthly sensible load for each of the summer months that was derived from the data supplied by Georgia Power. This is the same house that was used in the single level field evaluation.

Only sensible loads are used because the radiative cooling method employed in the Detached Earth Tempering Concept is not capable of carrying latent loads. Sensible loads were estimated by dividing the total hourly cooling load by 1.3.

The daily load profile for a given month was programmed into a Research Incorporated Model 73211 Micro Data Trak load programmer which controlled a Research Incorporated Model 63911 process controller with a 40 amp solid state switch. The solid state switch varied the power going to a General Electric 220 volt, 20478 Btu/hr (6 kw) electric circulation heater according to the programmed load.

Water was circulated through the buried field and through the water heater before returning to the field. The field was considered to be capable of passively cooling a building until the water temperature coming from the field rose above 74 F. The choice of 74 F was based on preliminary radiant cooling simulations which showed that comfort would decrease at radiator temperatures much above 72 F.

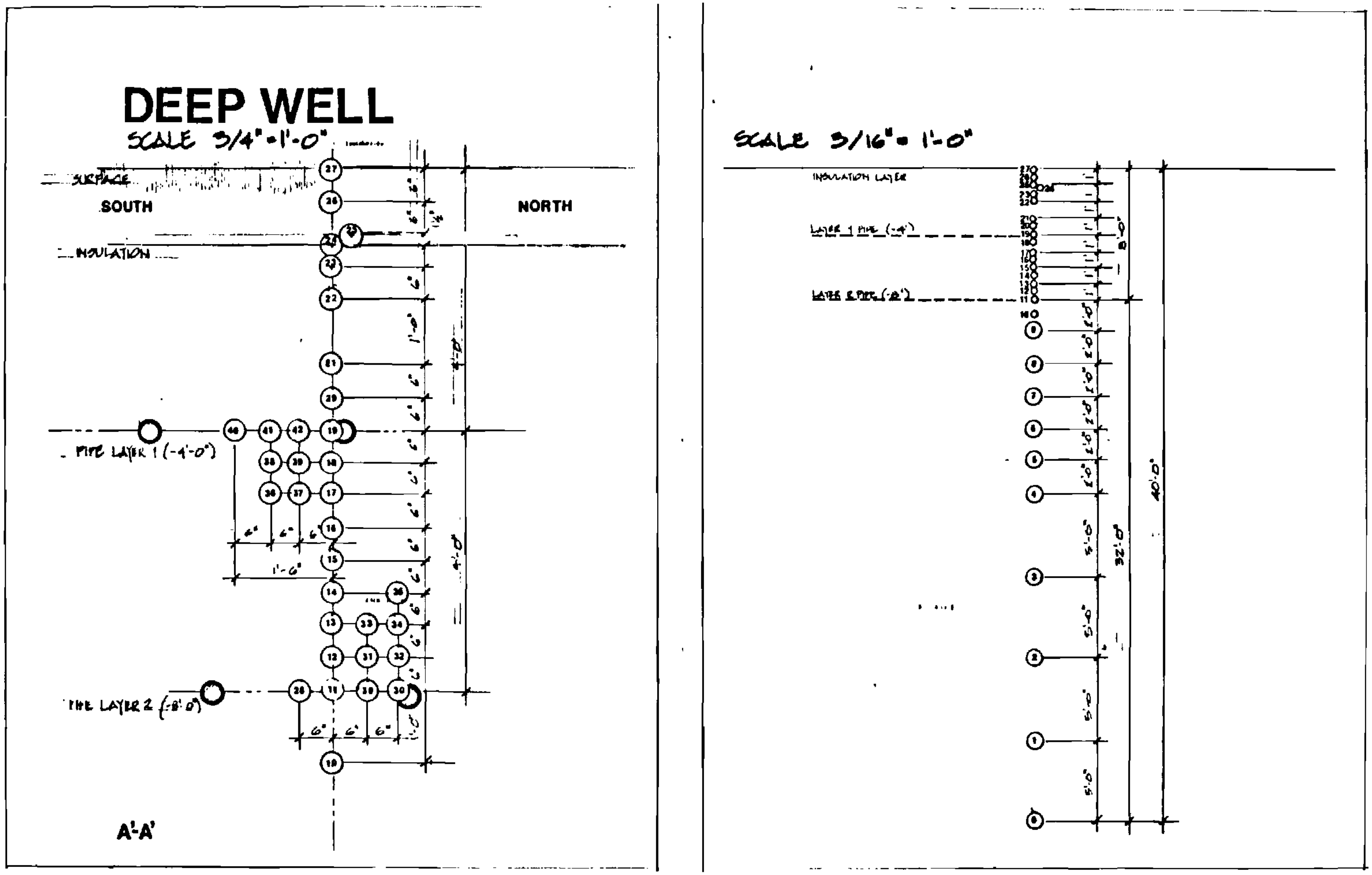


Figure 4. Instrumentation Layout in Cooling Field

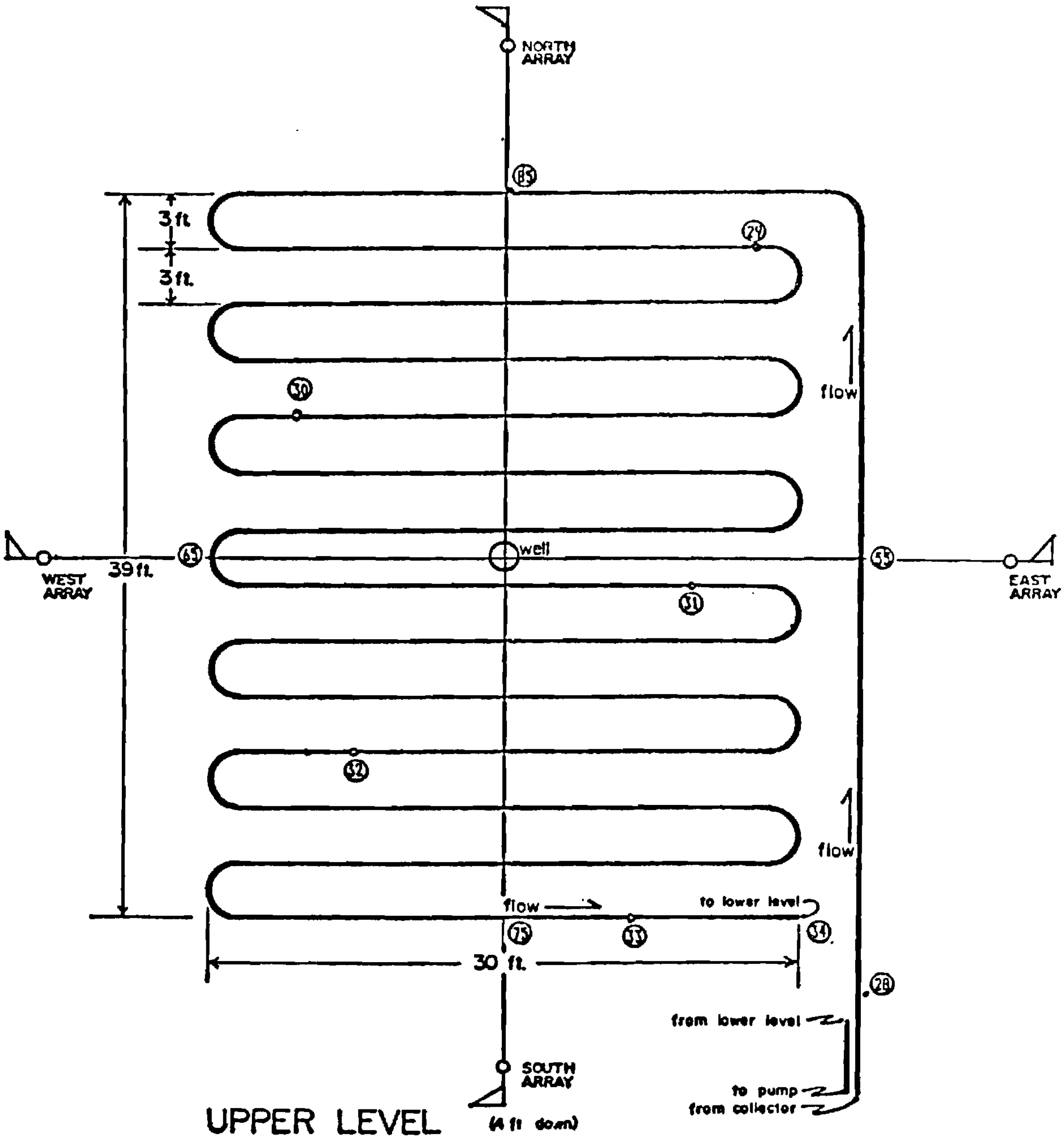


Figure 5. Plan View of Field at Four Foot Depth

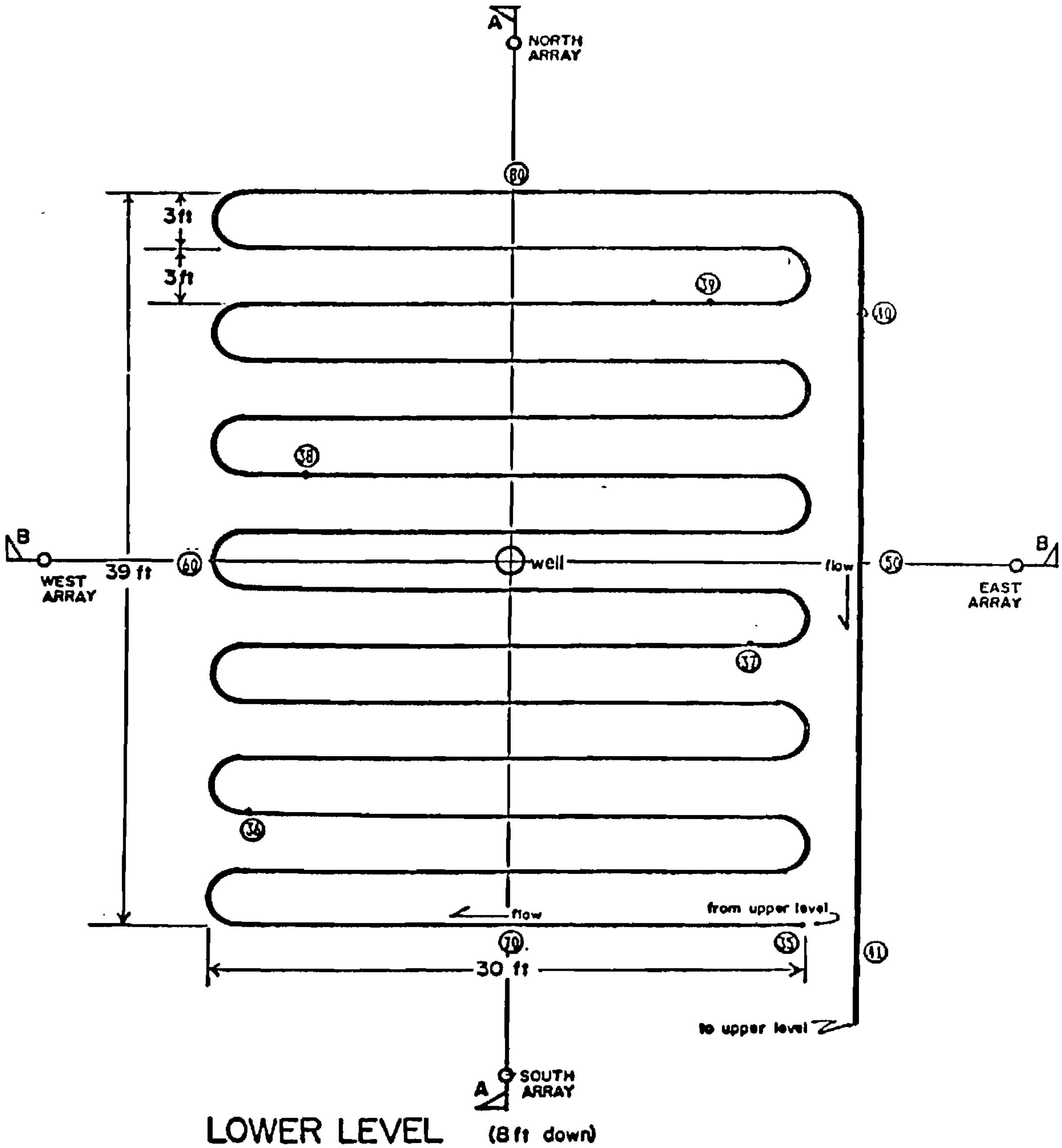


Figure 6 Plan View of Field at Eight Foot Depth

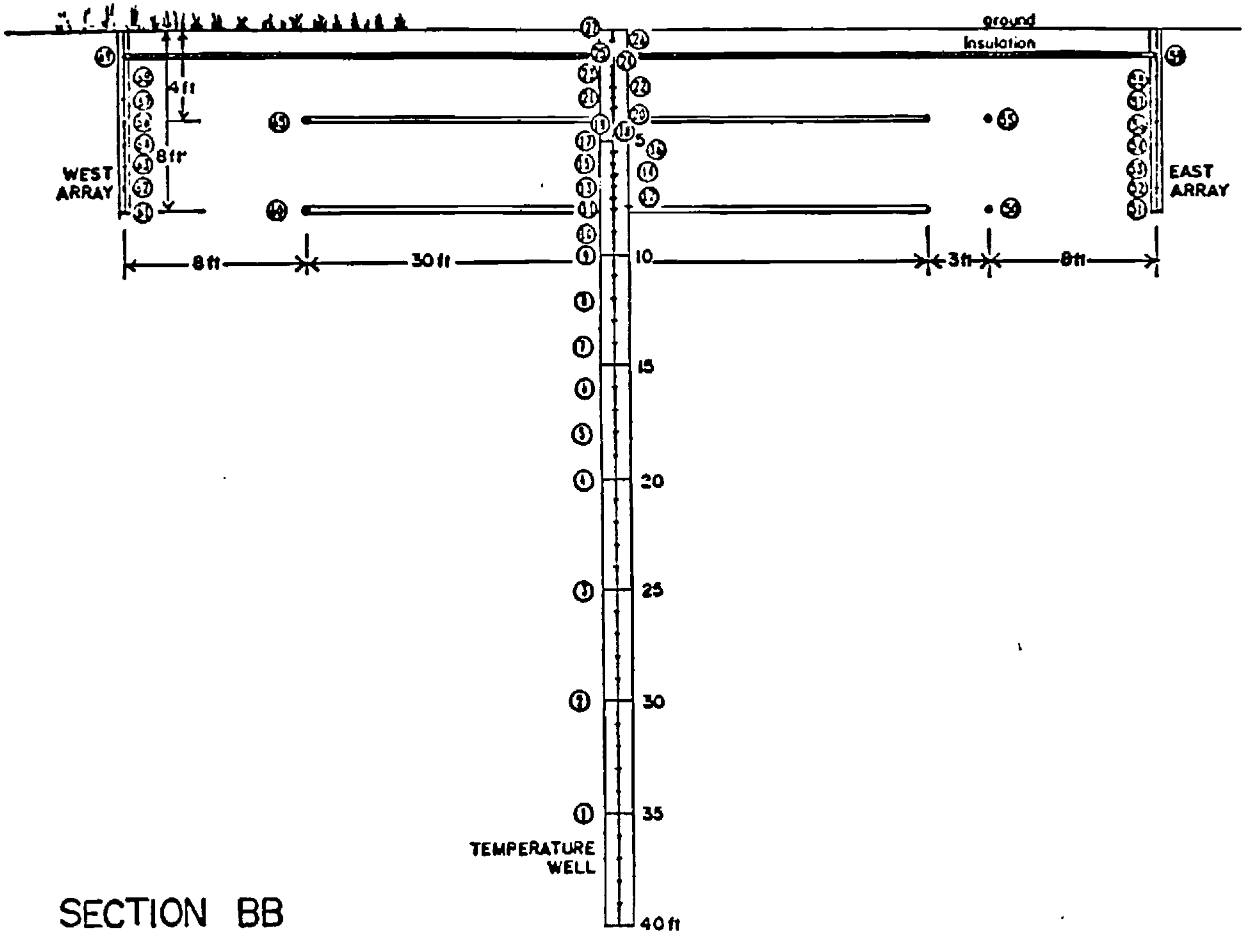


Figure 7. Cross Section of Field Looking East

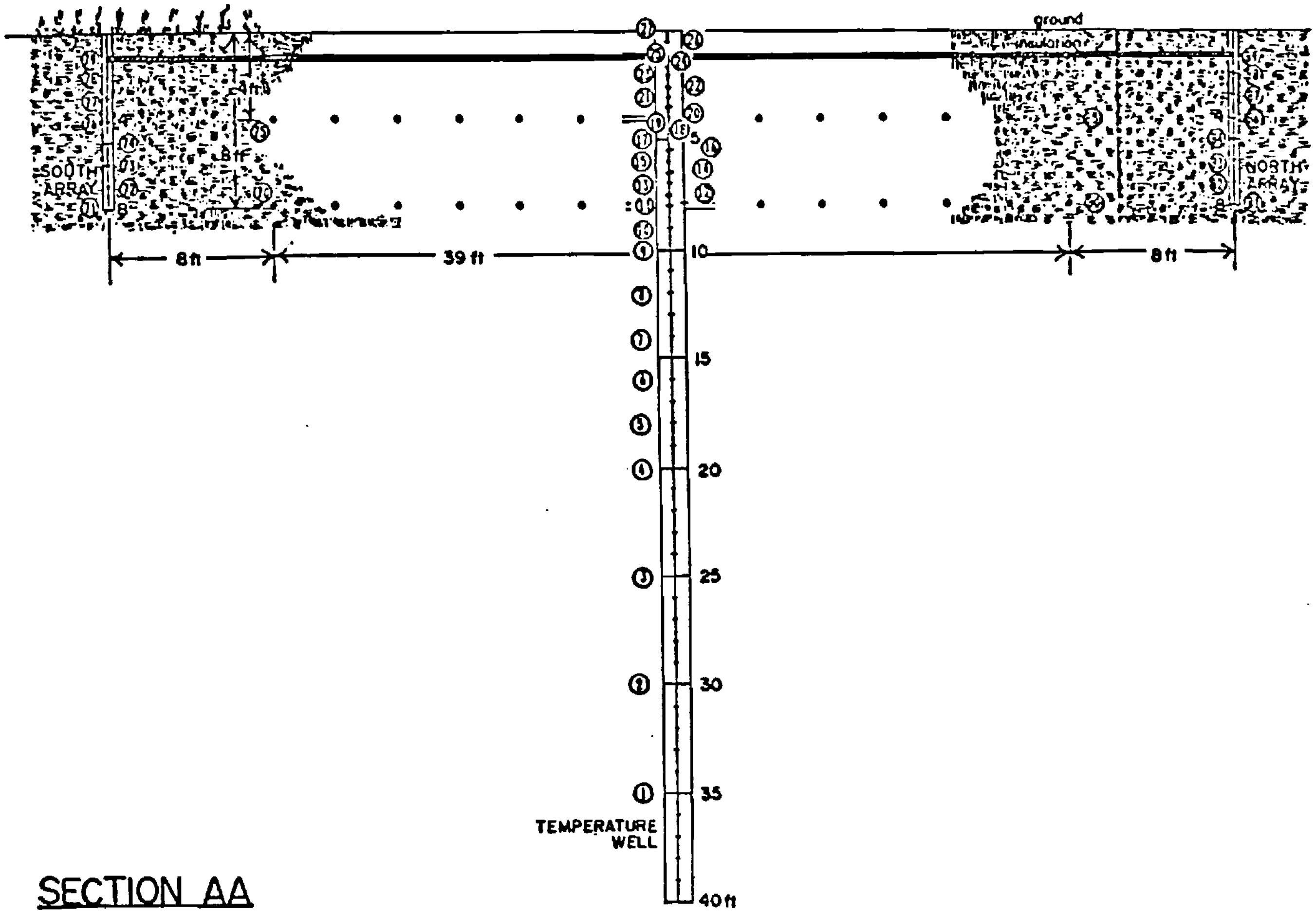


Figure 8. Cross Section of Field Looking South

TABLE I

| COOLING PERFORMANCE OF DETACHED FIELD | | | | |
|---|---|---|---|---|
| Month | Hourly Load (Btu/hr) | Daily Load (Btu/day) | Monthly Load (Btu/month) | % Monthly load |
| May | 1720 | 41283 | 1279793 | 100.0 |
| June | 3485 | 83632 | 2508964 | 100.0 |
| July | 3287 | 78881 | 2445318 | 100.0 |
| Aug | 2901 | 69625 | 2158381 | 100.0 |
| TOTAL LOAD CARRIED PASSIVELY | | | 8391187 | |
| Sep* | 6314* | 151537* | 4546116* | 100.0* |
| YEAR | | | 10253866 | 81.8 |

* September load was carried by a water-to-water heat pump which dumped load to the field. The September load was made artificially high to see how the field reacted to high continuous input.

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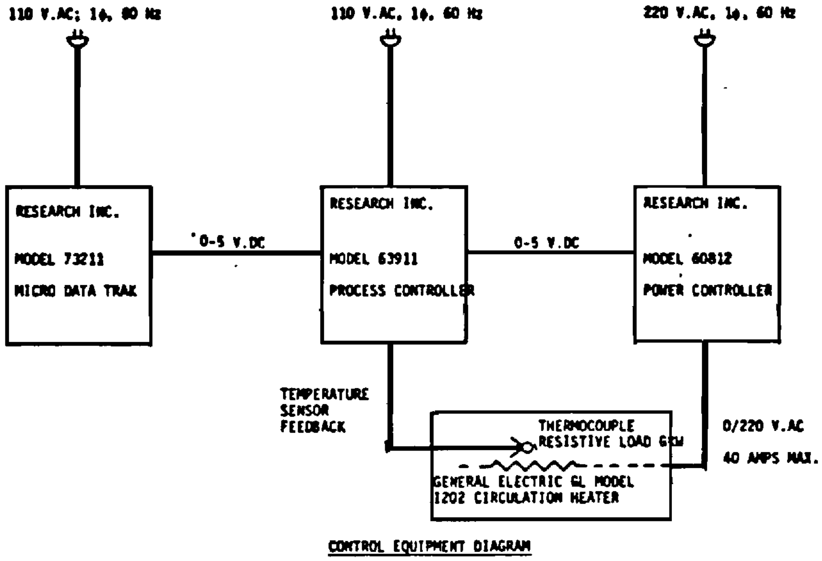



Figure 9. House Load Simulation Equipment Schematic

MEASURED PERFORMANCE

The field was initially installed with tap water as the fluid circulated through the field and the above ground heat exchanger because of fear that if leaks developed during the field checkout the ground water might be polluted if ethylene glycol were used. It was decided early in January 1983 that the system was not leaking and that the efficiency and reliability of the system could be improved by adding ethylene glycol to the water in the system. This permitted the system to run all hours when the ground temperature was above the air temperature without there being a concern that loss of power would cause circulation to stop and freezing to result. A sufficient amount of ethylene glycol was added to lower the freeze point of the circulating fluid to below 15 F.

The mild weather experienced during the early part of 1982-1983 caused the initial field cooldown to be less than expected. The above ground air-to-fluid heat exchanger was initially installed to depend only upon natural convection for the air-to-exchanger heat exchange. The mild weather prompted the installation of two 1/12 hp fans to the air-to-water heat exchanger in late February. The average field temperature at the time of the fan installation was 54 F, higher than one would expect at this time of the winter. The fans increased the exchange rate significantly and permitted the field to cool when the ambient air temperature was relatively close to the field temperature. Although a significant amount of energy was removed from the field, the field temperature didnot decrease significantly in subsequent days days due to diffusion of energy into the field from the adjacent soil. While this diffusion decreases the drop in temperature of the field, it also decreases the temperature of the soil adjacent to the field. Lower adjacent soil temperature is almost as useful for the detached earth tempering concept as lower average field temperature.

The single level field showed that the detached earth tempering concept might have problems meeting instantaneous peak loads such as one might encounter with an air heating system. The earlier study showed that with proper use of massive radiant cooling floors and high insulation levels the load profile of the house could be flattened with a nearly constant lower load for all hours. Rather than duplicate the hour-by-hour load profile experienced by the Columbus house, the monthly total load was divided by the total hours in each month and the resulting constant load was programmed into the Research Incorporated load controller. Table I shows the monthly load and the load and percentage carried by the detached cooling field. The stored cooling capacity of the field carried all of the May, June July and August loads without any auxiliary backup. When the temperature of the water coming from the field reached 74 F, the water coming from the field was diverted to the condenser of a water-to-water heat pump. Water from the evaporator of the heat pump was then directed to the building load simulator. The September load was then carried by the water-to-water heat pump using the detached cooling field as a thermal sink. The temperature of the water coming from the field at the conclusion of the tests was 84 F.

The tests show that the cooling potential stored in the detached cooling field can carry the cooling load of a moderately sized residence located in Georgia. One can calculate a COP for each of the months and for the complete season by dividing the cooling capacity delivered by the energy required to store that energy (pump plus fans) plus the energy required to deliver the energy (pump) and the energy required to operated the water-to-water heat pump. Table II summarizes the energy input to the system, the energy delivered to the system and the resulting COP for each month and for the year.

It is important to point out at this time that the water-to-water heat pump operated at a much lower COP than was expected. The particular pump used was a old model E-TECH unit which should have delivered COP'S well above 3.0 with the moderate water temperatures and the small temperature differences involved. The COP of the unit was measured at 2.1 if the pump energy was not included and dropped to 1.77 if one included the pump electrical input.

Despite the low heat pump COP the total system COP was very high. System COP during May, June, July and August varied from 6.4 to 10.9. All of the September load was carried by the heat pump. The total cooling COP was 3.4. Had a more efficient water-to-water heat pump been used the September and season COP's could have increased significantly.

## THEORETICAL PERFORMANCE

A computer program called GROCS was used to simulate the performance of the double level field. This program, developed by the Brookhaven National Laboratory and modified by these researchers has been previously shown to be very accurate in predicting subsurface heat transfer and the performance of buried horizontal fields. Appendix A gives a detailed description of how the model is setup and the

TABLE II

ENERGY INPUT TO SYSTEM

| MONTH | PUMP INPUT (Btu) | FANS INPUT (Btu) | HEAT PUMP INPUT (Btu) | TOTAL INPUT (Btu) | TOTAL DELIVERED (Btu) | COP |
|---|---|---|---|---|---|---|
| OCT | 38815 | | | 38815 | 0 | — |
| NOV | 35988 | | | 35988 | 0 | — |
| DEC | 41033 | | | 41033 | 0 | — |
| JAN | 44360 | | | 44360 | 0 | — |
| FEB | 33270 | | | 33270 | 0 | — |
| MAR | 16635 | 94711 | | 111346 | 0 | — |
| APR | 8872 | 50512 | | 59384 | 0 | — |
| MAY | 165019 | | | 165019 (201046) | 1279793 | 6.37 |
| JUNE | 159696 | | | 159696 (230325) | 2508964 | 10.89 |
| JULY | 165019 | | | 165019 (233857) | 2445318 | 10.46 |
| AUG | 165019 | | | 165019 (225779) | 2158381 | 9.56 |
| SEPT | 159019 | | 2629717 | 2788736 (2916713) | 4546116 | 1.56 |
| TOTAL | 1032745 | 145223 | 2629717 | 3807685 | 12937303 | 3.40* |

NOTE! Energy input for those months when the field was being charged was proportioned to those months when it was being used to calculate COP.

* The overall COP is low because the COP for the water-to-water heat pump was low.

simplifying assumptions used.

Figure 10 shows the field water discharge temperature at the end of each of the test months. The measured temperatures at the end of each month are also plotted on the figure. Notice that the predicted temperatures agree quite closely with the measured temperatures. Figure 11 shows measured average field temperatures for each month compared to those calculated for comparable depths. Much of the difference between the calculated and measured field temperatures resulted from a difference in the initial temperature at the first of May used in the calculations. Notice that cooling and heating the field significantly affects temperatures. It should be pointed out the the predicted temperatures are based on average ground temperatures while the measured pe was taken for a particular year.

## COUPLING DETACHED FIELD TO BUILDING

Passively cooling a building by using the ground as a heat sink has been popularly accepted in the form of underground, or "earth-coupled" structures. Directly coupling building elements such as the walls, floor, or ceiling to the earth has numerous disadvantages, among them the lack of control over the temperatures and heat transfer rates of the structural building elements. This lack of control leads to problems in hot-humid climates including condensation on walls in early spring, high wall temperatures in the fall and excessively cold surfaces in late winter. By decoupling the heat sink from the building element, control may be achieved over the building's interior temperature and the heat flow of the building element to the earth.

Earth coupled cooling requires a heat exchange element in the building that maintains its cooling efficacy at relatively high temperatures. Decoupling the earth from the building element and transferring heat from these interior surfaces to a cooling field with water allows the occupant control over the temperature of the space and improves the cooling potential of the earth. Radiant wall panel heat exchangers were identified as viable options. Preliminary experiments with concrete slab cooling panels indicates that mass incorporated in a radiant element yields more uniform panel temperatures and maximizes cooling field potential. Radiant coupling to a secondary mass increases the response time of the slab and maintains cool temperatures in the secondary mass.

Earth coupled cooling is characterized by low temperature differences between the earth and the space that requires cooling. For example, in Atlanta earth temperatures at the end of August at a depth of 8 ft. are approximately 68.9 F. This temperature, when directly coupled to building walls, will increase significantly due to the transfer of heat from the building to the earth. These relatively high cooling temperatures preclude the use of convective elements for maintaining comfortable air temperatures. Unless coupled to a mechanical cooling mechanism capable of producing a large temperature potential between the interior air and heat exchange fluid, convective heat exchanges, when coupled with earth heat sinks, play a secondary role to

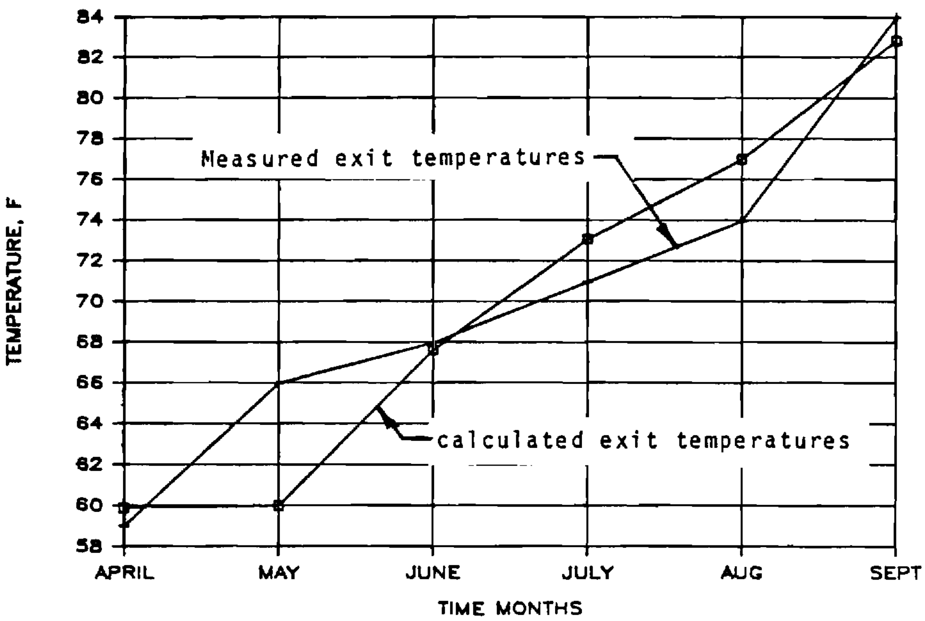



Figure 10 Field Water Exit Temperature

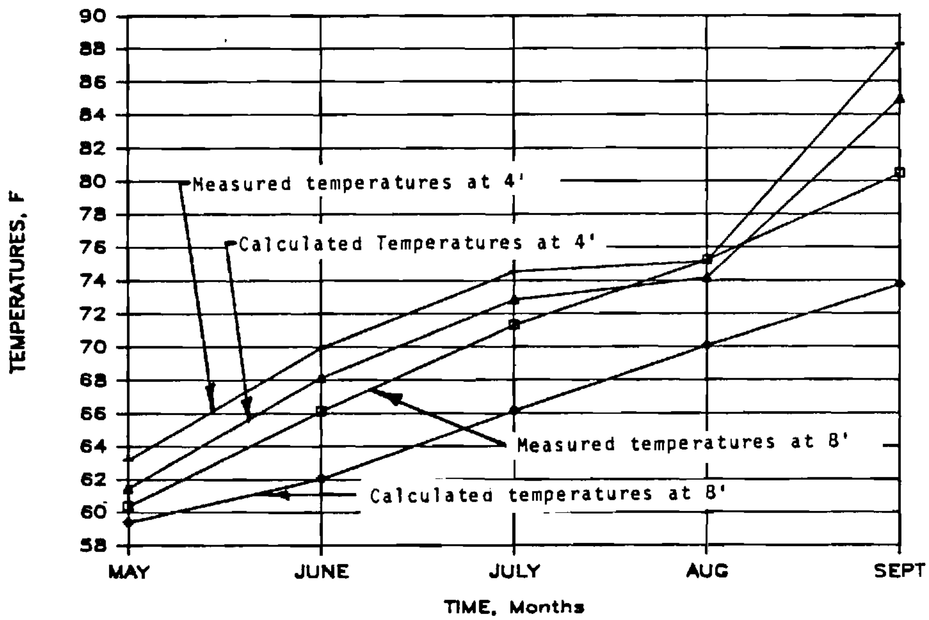



Figure 11 Field Block Temperatures

radiant heat exchange.

As stated earlier the computer studies showed that cooling capacity from a buried field might be incapable of meeting peak instantaneous loads but would be adequate for average daily loads. This indicated that optimum performance could not be obtained using low mass radiant planes. Although considerable data have been published in the literature directed toward the design of radiatively heated buildings, there are little data on design of radiatively cooled buildings. ASHRAE provides some design guidelines using light weight radiatively cooling panels.

The Detached Earth Tempering concept consists of two elements: 1. an earth coupled element and 2. a building side heat-exchanger. Polyethylene pipe buried below the surface transfers heat from the building's interior to the ground. The block of earth associated with the pipe is separated from ambient temperatures by a two inch extruded polystyrene insulation one foot below grade. Temperatures in the test field have ranged from 54 F in early spring to 84 F in late July with simulated building cooling loads applied to the field. Field temperatures limit the type of heat exchangers practical in residences and also limits the rate at which heat may be instantaneously removed from a building.

Radiant space conditioning panels are capable of maintaining comfort conditions with higher temperatures than forced air systems due to a reduction in mean radiant temperature caused by the cool panel.

The radiative cooling potential of concrete walls of several thicknesses with several different tube spacings have been simulated using a thermal simulation program called MITAS2 and a smaller thermal network program for microcomputers called T-NODE3. These simulations show the radiative cooling concept to have potential as a method for coupling low grade cooling capacity to a building.

Preliminary calculations showed that the detached cooling field could be most easily coupled through a concrete slab floor. Since concrete floors may not be satisfactory from a consumer standpoint in all cases, different methods of coupling the field to the house were extensively explored. The two most promising methods are discussed below

Radiant Cooling Floors

Figure 12 shows the model used to simulate the performance of the detached cooling field when coupled to the house through a concrete floor. Assuming a building UA of 350, house performance for an outside maximum temperature of 92 F and minimum temperature of 72 F was determined. Figure 13 shows that the inside temperature only varies by 2.5 F while the outside temperature is varying by 20 F. An inside air temperature of 78 F can be maintained with a floor temperature of 76.5 F.

This particular simulation assumed that the house was built above the cooling field and was only isolated from the field by 2"(R9) of insulation located 1 ft. below the floor and 3' above the top level of

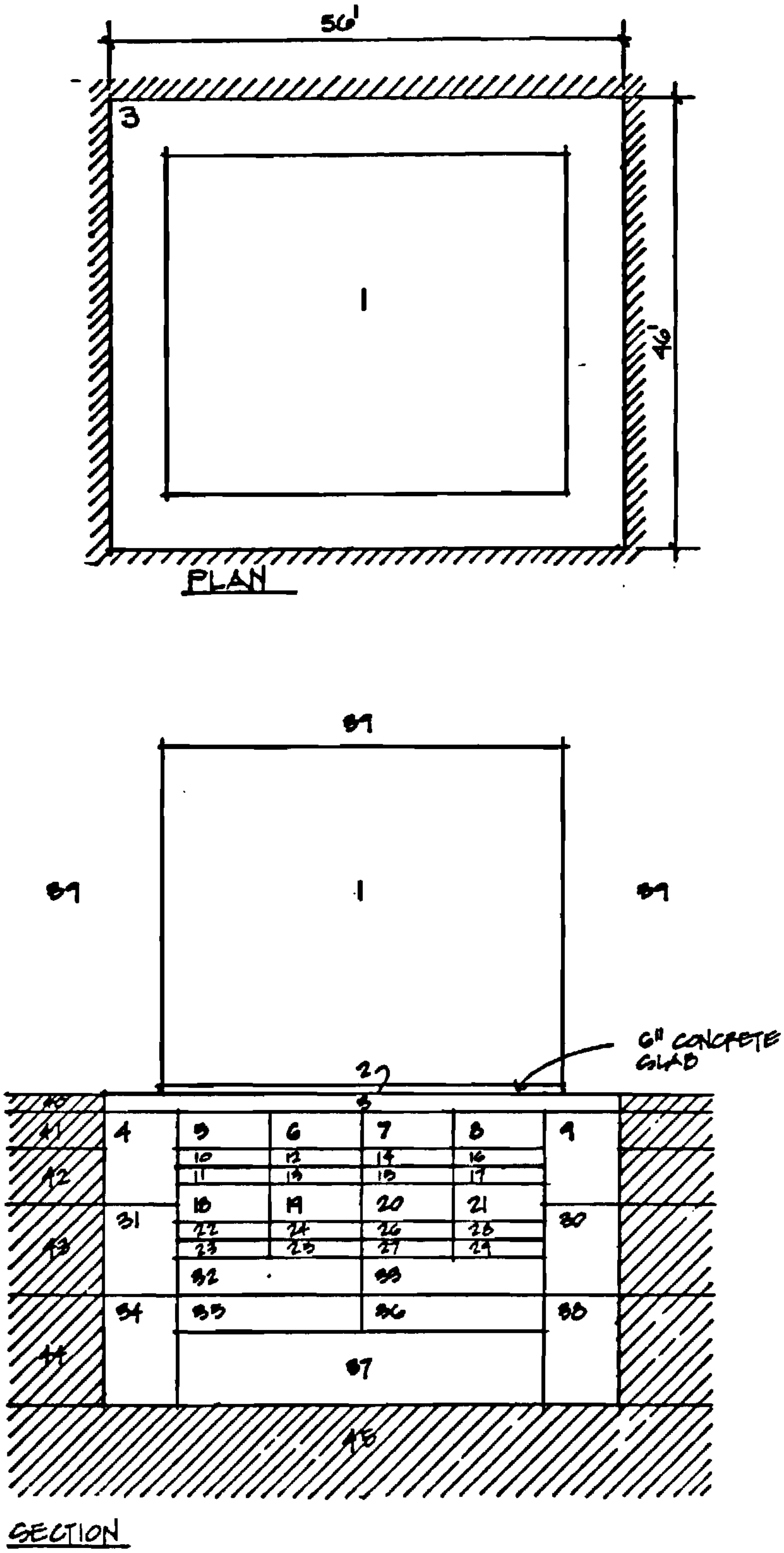



Figure 12 Model Used to Simulate an Underhouse Field

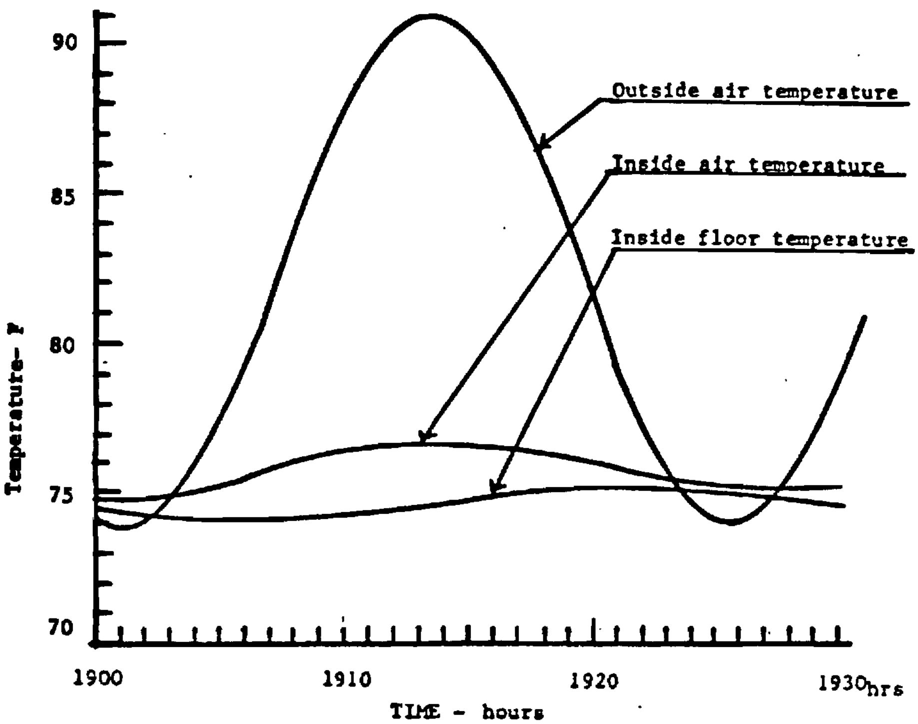



Figure 13. Thermal Performance of Slab Coupled House

the subsurface tubing in the field. This works well during the middle to later part of the summer but tends to overcool during the later part of the winter and early part of the summer. One doesn't have sufficient control over the system to properly match the cooling loads. This simulation assumed that the entire floor area acted as a radiator and that the floor was not covered by carpet or other thermal resistance.

Radiant Cooling Walls

Because every house is not adaptable to concrete floor or slab on grade construction, several simulations were made for crawlspace construction with radiant cooling walls as the means for coupling the house to the detached earth cooling field. Use of radiant cooling walls made by Solar Wall Limited was assumed in all radiant cooling wall simulations. Figures 14 and 15 show several views of these walls. These were chosen because they have the best storage capacity, the easiest circulation mechanism, the best coupling to the inside air and are the easiest to assemble of any considered. These walls are semicommercially available where all of the other cooling walls required special construction.

Figure 16 shows the model used to evaluate the performance of the cooling walls. This model is a close approximation to a house being considered for another program. This simulation provided a good mechanism for evaluating not only the performance of the cooling wall, but performance of the house as well. This house has a UA of 333, a floor area of 2500 sq.ft. and uses 49 of the 2' x 9' cooling panels. The radiant cooling area of the 49 panels was reduced by 20% to account for coverage by poorly conducting surfaces or poor coupling to the space being cooled.

Figure 17 shows the predicted cooling performance of the wall when the house was subjected to an outside temperature varying from 79 F to 97 F. Thermal radiation through the 256 sq.ft. of windows was also included in the load experienced by the building. Notice that the inside air temperature changes from a low of 74.5 F to a high of 76.2 F. Use of the cooling wall and the low building UA kept the building load experienced by the field between 7718 and 8869 Btu/hr. It should be noted that the use of the massive cooling wall reduced the peak thermal load on the mechanical system from 17,500 Btu/hr. to 8869 Btu/hr, while the surface temperature of the wall varied only 1.0 F. A water supply temperature of 65 F was sufficient to meet the building peak load and keep the inside air temperature below 77 F. Notice that the required water temperature is lower than the floor surface temperature in the slab floor simulations discussed above. This difference comes from the reduced surface area used in the cooling wall and the thermal resistance of the concrete between the water and the air. The wall surface temperature only varied from 69.7-70.5 F to keep the air temperature below the 77 F discussed above.

The great advantage of a radiant cooling system coupled with a low building UA lies in its ability to provide either heating or cooling with very little change in the temperature of the water supplied to the wall. This keeps the building from experiencing overcooling or overheating when outside conditions require the building to go from

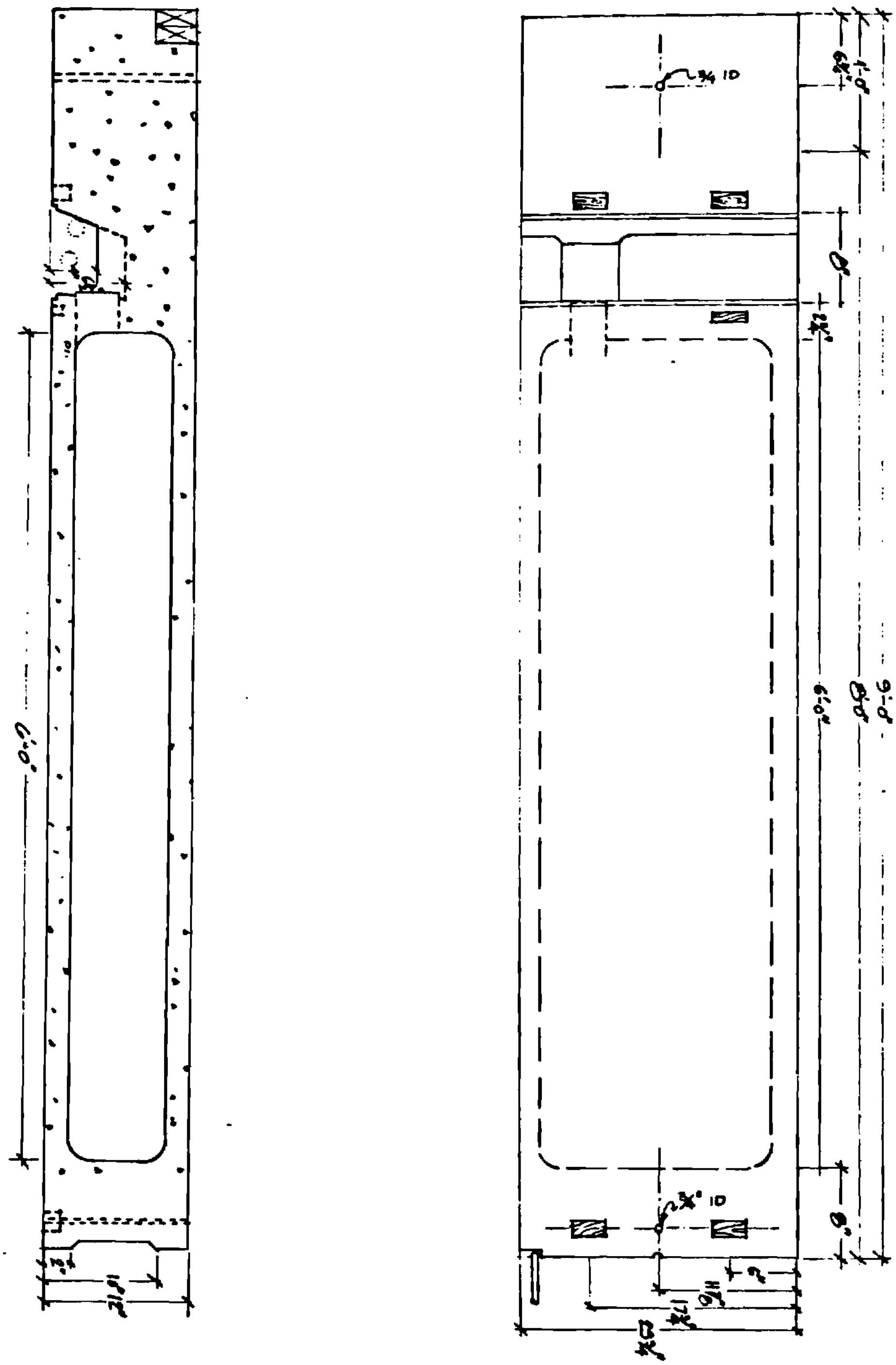


Figure 14.- Section and Front Elevation of Cooling Wall Panels

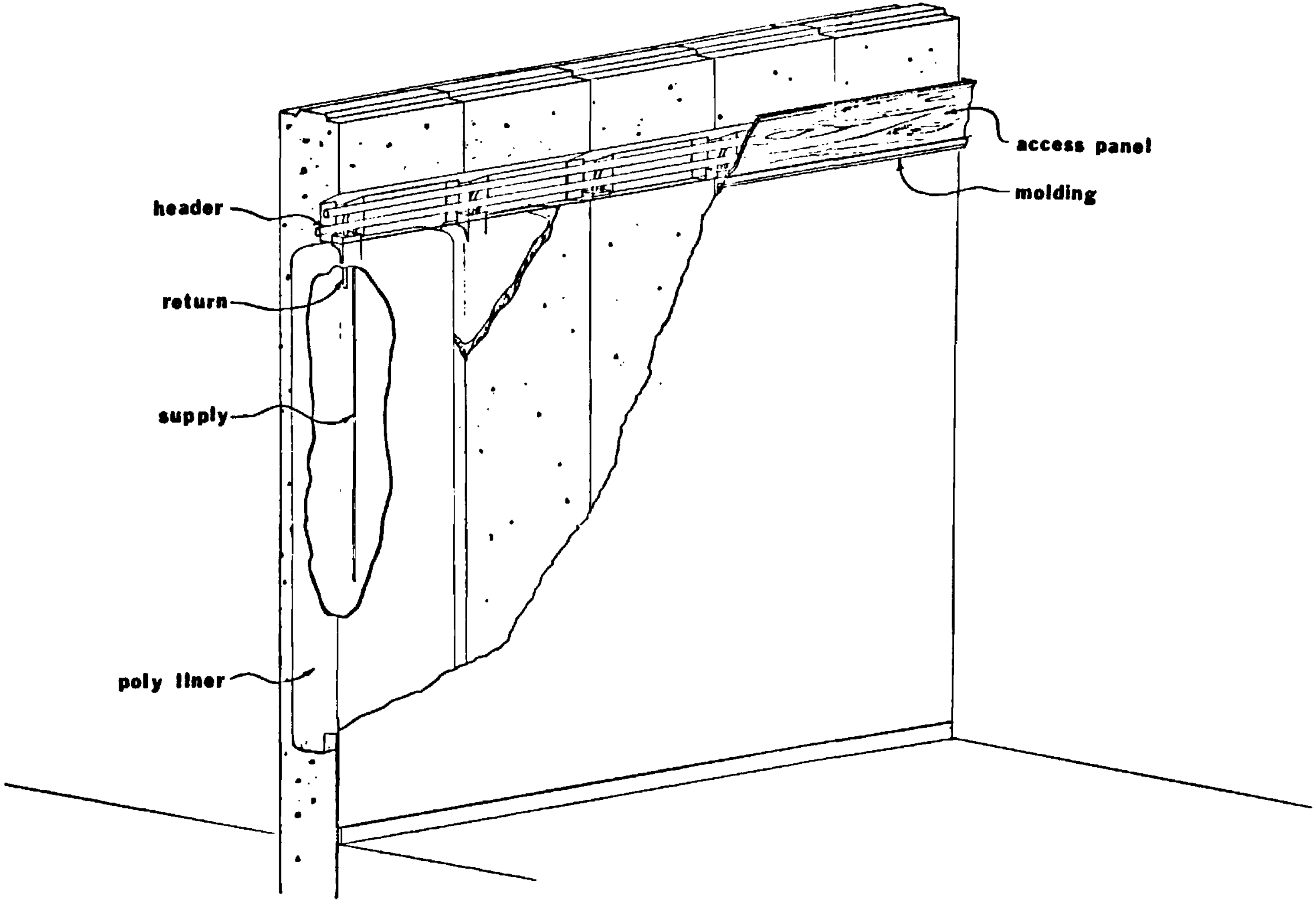



Figure 15. Cooling Wall Assembly

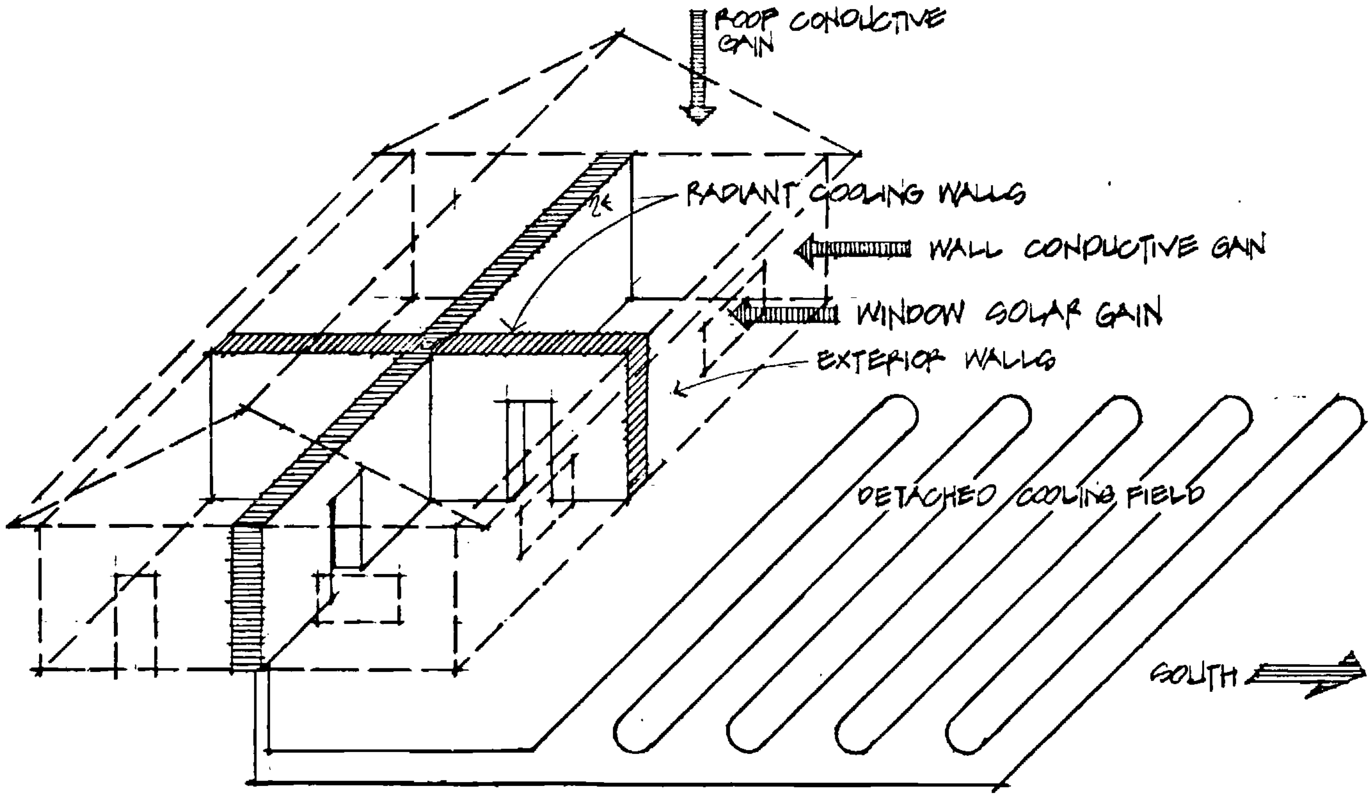



Figure 16. Model Used for Simulating Performance of Cooling Walls

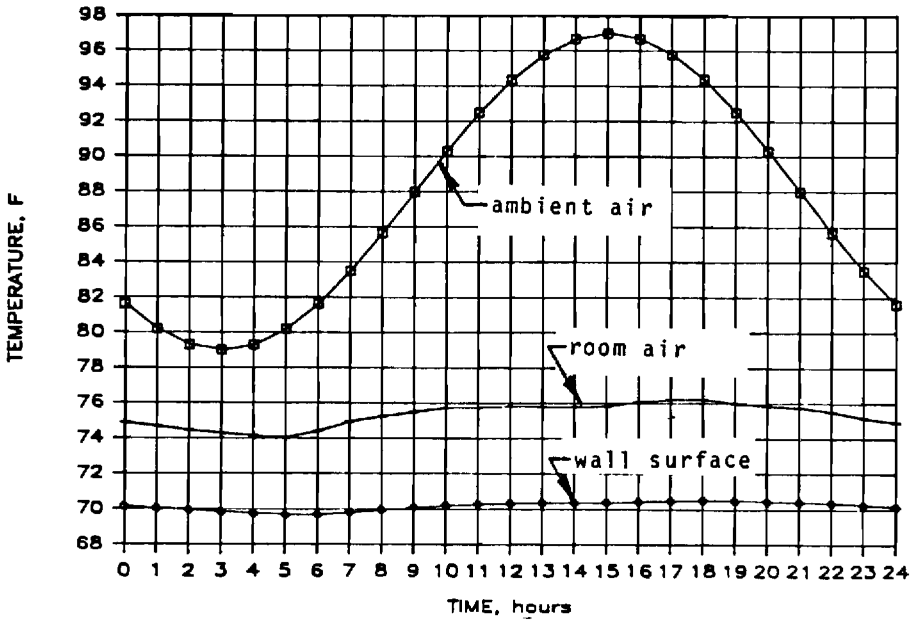



Figure 17 Thermal Performance of Cooling Wall

either heating to cooling or from cooling to heating.

Simulations on this building also examined large relatively short term thermal inputs such as might result from large internal gains associated with, say, a party. The simulation showed that the great mass of the wall prevented the internal gains from affecting the internal air temperature more than 0.5 F.

These simulations did show that significant additional work is necessary to develope the control strategy for the thermostat. A simple thermostat which monitors the room air temperature will not provide input sufficiently early to adjust the water supply temperature or water supply rate. It appears that a microchip controlled thermostat which looks at the rate of change of the wall surface temperature will be necessary to provide the optimum comfort in a space heated or cooled with a massive radiant wall.

These simulations show that the massive radiant cooling concept has considerable potential to provide high efficiency cooling. They show that the walls when combined with highly efficient buildings (low UA) have the potential to significantly reduce peak loads which impact the electric utility's capacity requirements for residences.

AUXILIARY SYSTEMS

It is imperative that passive cooling systems work well, or at least not interfere, with passive heating systems. It is also important that both passive heating and cooling systems be complemented with efficient auxiliary heating and cooling systems. Nothing useful is accomplished if much of the energy one saves with passive heating and/or cooling systems is lost through the use of inefficient auxiliary systems. Unfortunately many advocates of passive systems are opposed to incorporation of state-of-the art or high technology mechanical systems as a backup. This usually results in poor efficiency and less comfort.

It was felt from the start that it would be highly unlikely that a passive cooling system for hot-humid climates could be developed which would be capable of meeting 100% of a residential cooling load. This means that an auxiliary cooling system is necessary if comfort is to be maintained. It is also felt that passive techniques for meeting latent cooling loads are not likely to be developed in the near future. If the sensible cooling load of a building is to be met radiatively in a humid climate it is imperative that latent loads be efficiently handled. Auxiliary systems must handle latent loads at all times, as well as both sensible and latent loads during extreme periods.

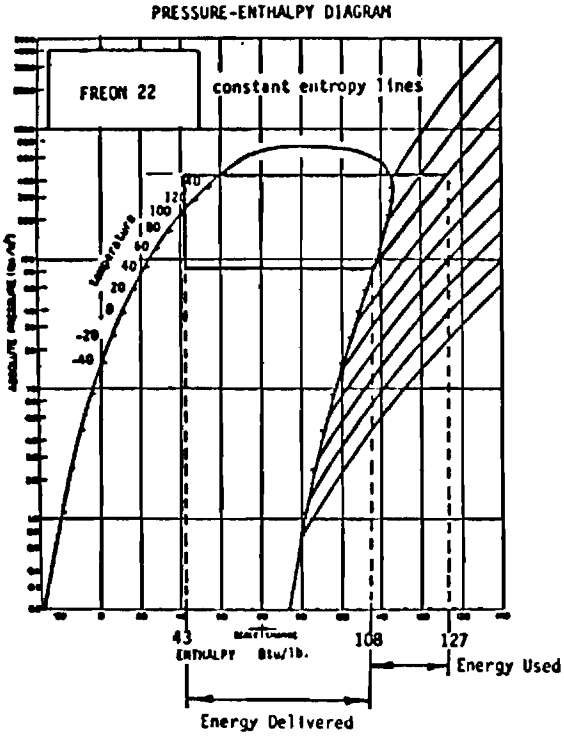
Unfortunately, if one employs a conventional air conditioner to handle the latent load, it also provides sensible cooling which can be provided passively. Greater efficiency can be obtained by handling the sensible and latent loads with separate equipment, rather than with a single component as is normal practice.

Auxiliary Sensible Load

If one plots an idealized Rankine cycle air source air conditioner on a pressure enthalpy diagram one would have a cycle such as shown in Figure 18. The coefficient of performance (COP) would be about 3.42 for the most efficient systems presently available. One is limited to this COP by two factors. Due to high ambient temperatures, one must have condenser temperatures of 150 F or above to dissipate the energy removed from the residence to the ambient air. Evaporator temperatures must also be at or below 50 F to adequately handle the latent load.

Use of a conventional air-source heat pump does not meet our stated desire to handle the sensible and latent loads separately. One can meet the sensible cooling load passively until the temperature of the water coming from the cooling field reaches 72-74 F. If one now supplies the 72-74 F water coming from the field to the condenser of a heat pump and supplies water from the heat pump evaporator to the cooling walls, one can function with a Rankine cycle similar to the one shown in Figure 19. Notice it is now not necessary to operate the condenser at 150 F because of the 72-74 F water available from the field. It is also not necessary to operate the evaporator at 50 F because the radiative cooling wall works well with 65-70 F water. One now has a auxiliary sensible cooling system with a COP of 6.0. Figure 20 gives a schematic of the cooling field and cooling wall when operating through the water-to-water heat pump.

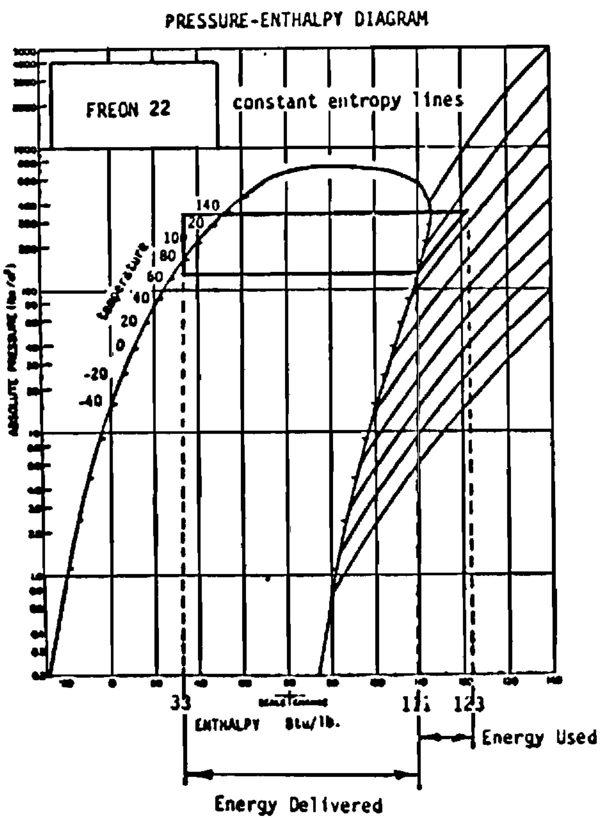
Similar cycles can be shown for a conventional heat pump and a water-to-water heat pump in the heating mode. One finds the heating COP improves from 3.10 to 6.92 by going to a water-to-water heat pump, obviously meeting our requirement for a high efficiency sensible auxiliary system compatible with the passive system.




$$COP = \frac{\text{ENERGY DELIVERED}}{\text{ENERGY USED}}$$

$$COP = \frac{108-43}{127-108} = 3.42$$

Figure 18. Idealized Air Source Heat Pump Rankine Cycle




$$COP = \frac{\text{ENERGY DELIVERED}}{\text{ENERGY USED}}$$

$$COP = \frac{111-33}{124-111} = 6.0$$

Figure 19. Idealized Water-to-Water Heat Pump Rankine Cycle

## HP DHW Heaters

If one succeeds in passively heating and cooling a residence completely one finds that a substantial energy requirement still remains. It is not uncommon for domestic hot water (DHW) energy requirements to exceed the heating and cooling requirements for well designed energy efficient conventional homes. The heating and cooling load given in the Building Energy Performance Standards proposed several years ago specified an annual heating and cooling budget of 5.2 million Btu and an annual DHW budget of 54.6 million Btu.

Solar DHW heaters are one solution to this problem, but one usually finds solar DHW installation costs to run from $2500-3500. Recently several manufacturers have begun to market DHW heaters which operate on the heat pump principle. These heat pump DHW heaters require only 35-50% as much energy input as required by conventional electric DHW heaters and can be purchased for $550-650. Since active solar DHW heaters become quite expensive when designed to deliver more than 60% of the total energy requirements, the heat pump DHW units are able to deliver comparable percentages at unit costs less than 30% of solar units. Figure 21 gives a schematic for a heat pump DHW heater.

Since the heat pump DHW units are very small and easily moved, it is possible to locate the units within occupied spaces. This makes it possible for the unit to not only meet the DHW needs, but also provide sensible and latent cooling as a side benefit. Notice that the unit is essentially a small water source heat pump which takes the energy removed from the space being cooled and adds this energy to the domestic hot water. This is very similar to the energy reclaim units added to conventional heat pumps.

## AUXILIARY LATENT LOADS

### Run-Around Cycle

One encounters conditions in passively cooled buildings where it is desirable to lower the dewpoint temperature without lowering the dry-bulb temperature. Unfortunately, conventional mechanical dehumidifiers are very inefficient (always operating at a COP less than one). Figure 22 shows the component layout and basic operating mode of conventional dehumidifiers. Notice that all the energy removed by the evaporator is added back to the air at the condenser, including the latent energy resulting from the water removal and the work required to move the energy.

Conventional air or water source heat pumps are capable of much higher COP's. Figure 23 shows the component layout and basic operating mode of a water source heat pump using well water as a source and a discharge well as receiver. A water source heat pump will provide both sensible and latent cooling which in some cases may be undesirable.

In those cases where dehumidification is the desired product one must modify the conventional heat pump cycle. The run-around cycle or the addition of run-around coils to a new system or to an existing system is one very good way to increase system latent capacity without

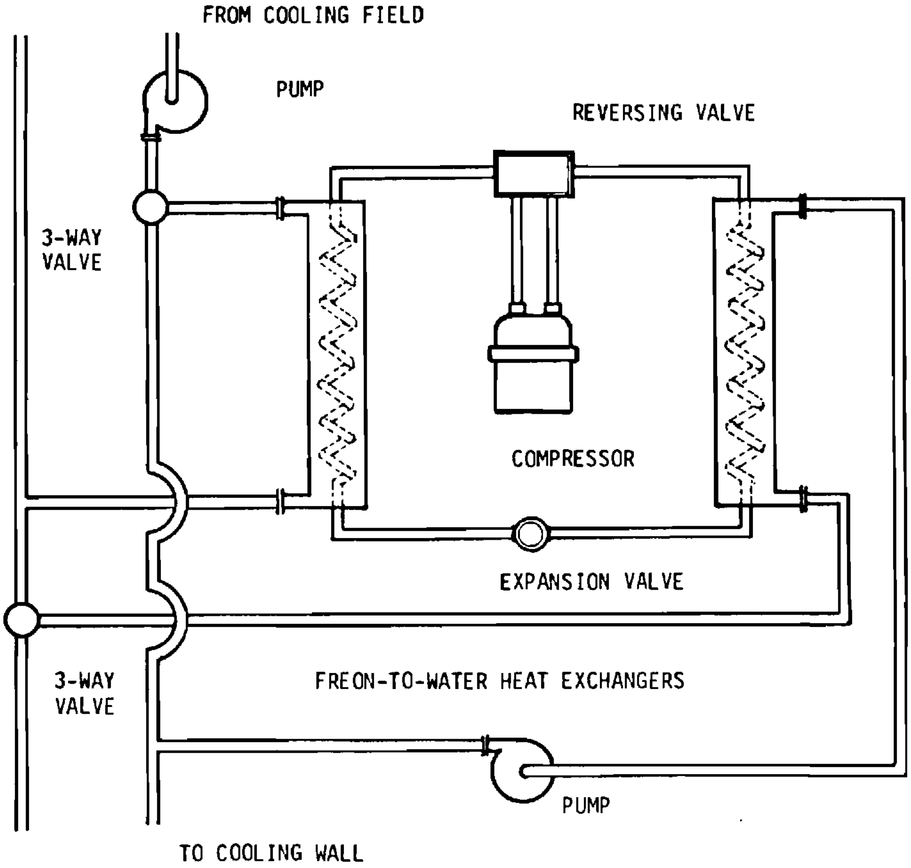



Figure 20. Cooling Field Operating Through Water-to-Water Heat Pump

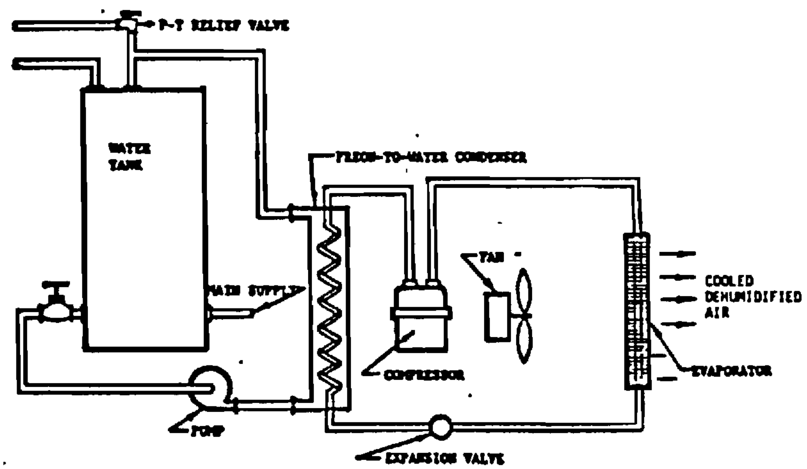



Figure 21. Water-to-Water Heat Pump Domestic Hot Water Heater

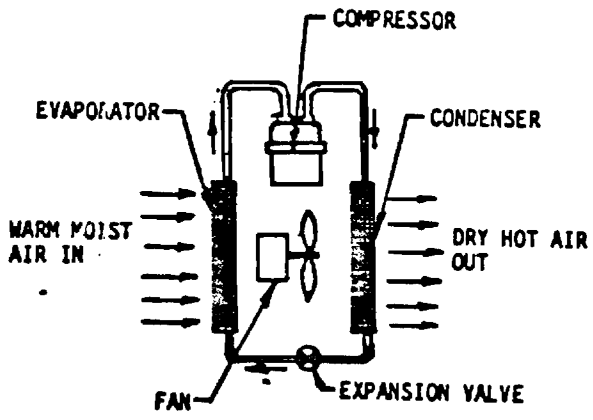



Figure 22. Layout of Conventional Dehumidifier

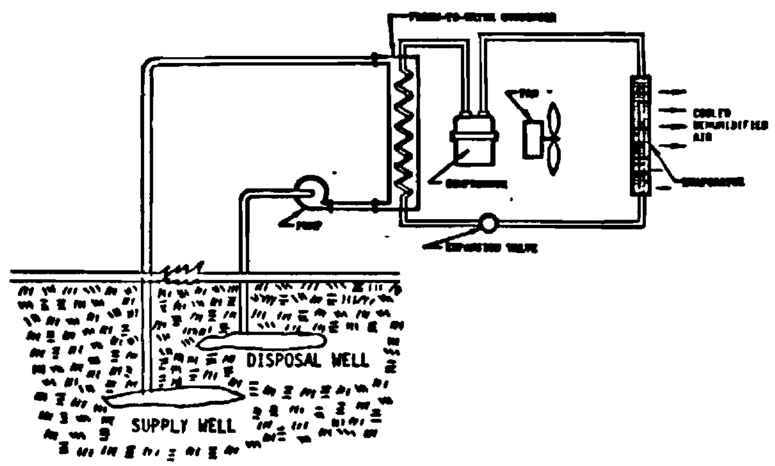



Figure 23. Water Source Heat Pump Using Well Water

increasing the system total capacity. This cycle has the advantage of low operating cost, compared to other methods of increasing latent capacity.

Figure 24 shows the basic run-around cycle. Water is circulated between two water-to-water heat exchangers, one located on each side of the mechanical system's cooling coil. Sensible heat withdrawn from the warm air on its way to the cooling coil is carried by the circulating water to the reheat coil. The reheat coil then returns the sensible heat to the chilled air leaving the cooling coil. Any sensible heat added to the flowing air by the reheat oil is exactly equal to the heat removed by the precooling coil. Consequently, there is a decrease in the refrigeration required to reach a given dewpoint temperature when using the run-around cycle.

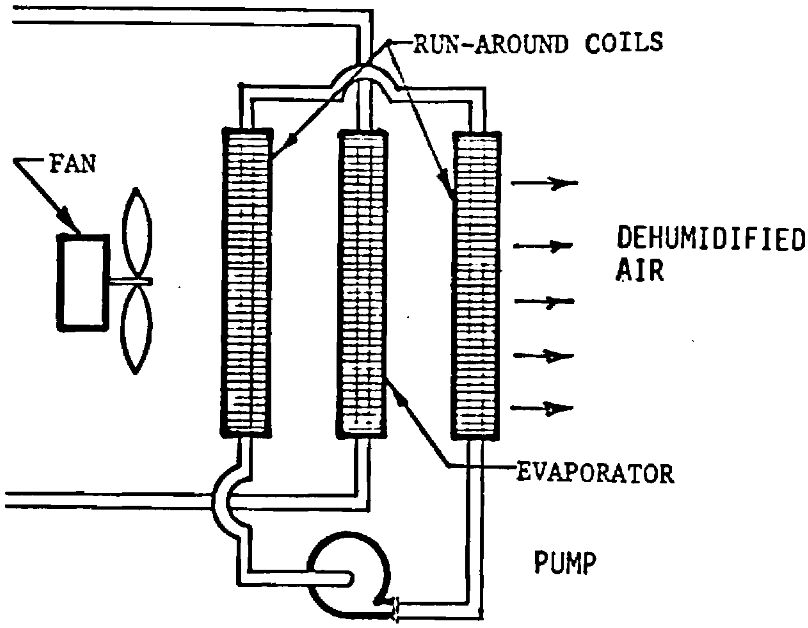



Figure 24. Basic Run-Around Cycle

Figure 25 shows the conventional dehumidifier cycle drawn on a psychrometric chart, while Figure 26 shows the heat pump cycle with a run-around coil added. Notice that the final air temperature with the conventional dehumidifier is higher than the initial temperature although the moisture level has been lowered. Figure 26 shows that when added to the conventional heat pump the run-around cycle results in dehumidification with some sensible cooling. Point "A" in Figure 26 is the final air condition for the heat pump without the run-around coil.

Passively cooled buildings are frequently able to carry the sensible load but are unable to meet the latent load. If conventional mechanical systems are added to these buildings, the mechanical system will carry both sensible and latent loads. Sensible loads should not be carried by mechanical equipment if they can be carried passively. Addition of a run-around coil will shift the mechanical system toward more latent cooling and less sensible cooling, thus improving system efficiency.

As discussed earlier it is desirable to provide sensible cooling using passive means. If sensible cooling can be accomplished passively, mechanical sensible cooling, even if it is a by product of a domestic hot water heating unit, decreases the load that can be carried by the passive system. This suggests that it is desirable to decrease the heat pump DHW unit's sensible cooling capacity and increase its latent cooling capacity. Figure 27 shows a schematic of a unit which has been modified through the addition of a run-around coil as discussed above. The run-around coil increases the latent capacity and decreases the sensible cooling capacity without significantly affecting the efficiency of the system. This now permits one to heat their domestic hot water efficiently, dehumidify (latent cool), and still provide the sensible cooling passively. If one looks at the combined efficiency of this system, one finds that the system COP is now about 5.0.

We now have an efficient DHW heater, a very efficient sensible auxiliary system and a latent auxiliary system which is a by-product of the DHW heater.

## ADVANCE MODE OF OPERATION

Once the auxiliary heating and cooling systems have been integrated into the passive design, one finds that a second and possibly better mode of operation becomes possible. One can passively cool with cooling potential stored in a block of earth until the water from the cooling field reaches approximately 74F. When the water reaches 74 F one actively cools with a water-to-water heat pump using the relatively cool 74 F water from the cooling field. This increases the field temperature until it reaches perhaps 100-110 F by the end of the summer. It should be noted that the temperature reached by the detached earth tempering field is highly dependent upon the size of the field and the load imposed on it. The detached field evaluated here reached only 84 F at the end of the cooling season because of the size of the field relative to the load imposed on it. One can now passively heat using the 100-110 F water coming from the field and the radiative cooling/heating wall. When the water coming from the field reaches approximately 80 F, the water is directed through the water-to-water heat pump and the heat

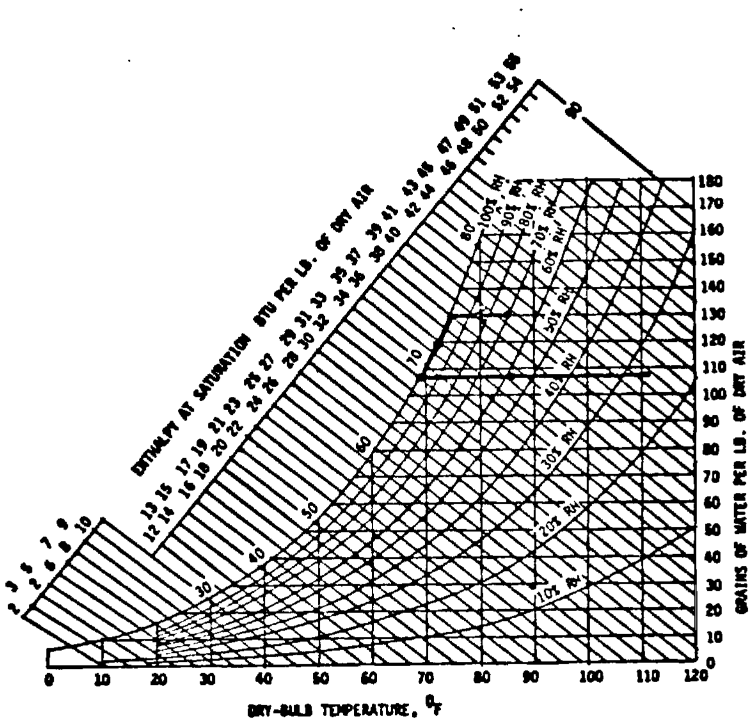



Figure 25. Conventional Dehumidifier on Psychrometric Chart

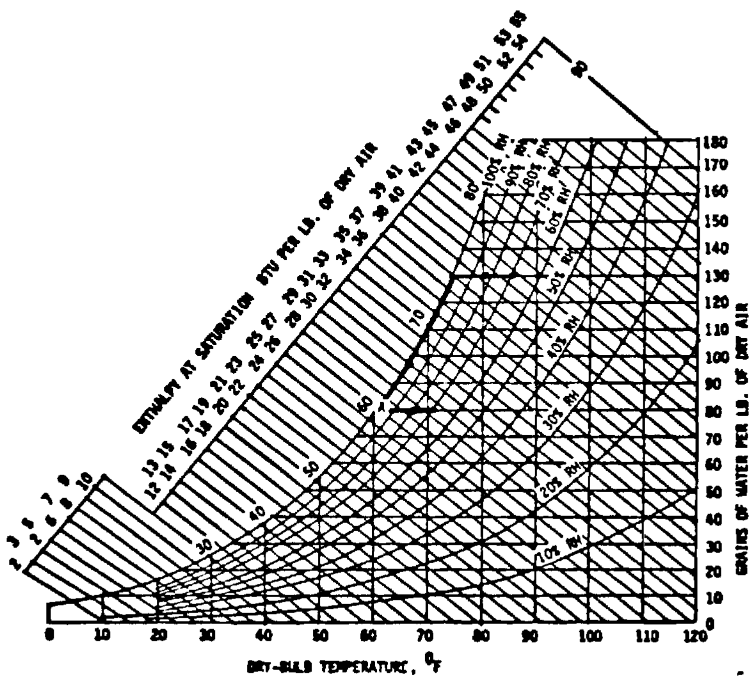



Figure 26. Heat Pump with Run-Around Coil Added Shown on Psychrometric Chart

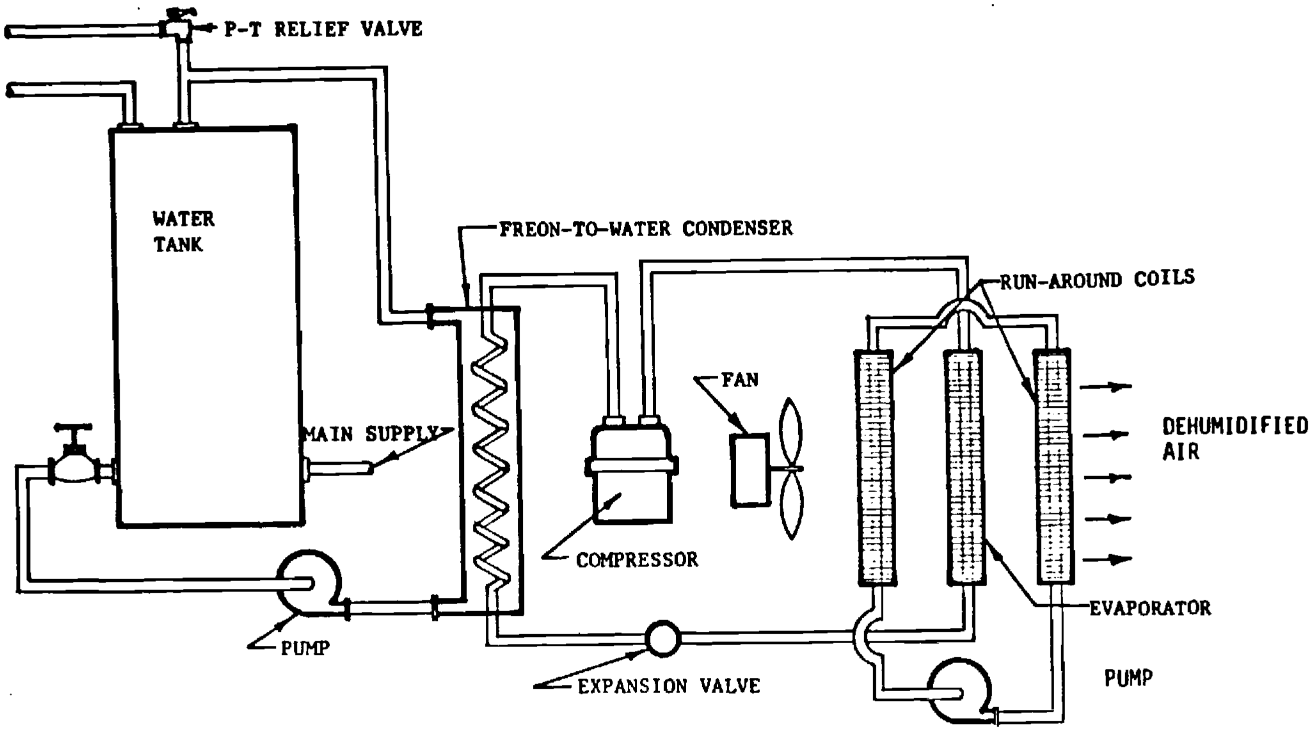



Figure 27. Heat Pump DHW Heater with Run-Around Coil

pump used to heat through the radiative wall. This cools the field until at the end of the winter the field has been cooled to perhaps 40-50 F. The system is now ready to begin another complete cycle. One now finds that the air-water heat exchanger described earlier and shown in Figure 3 is not needed under the new operating mode.

Obviously the cycle will not operate exactly as described due to energy diffusion during the spring and fall. Energy diffusion only changes the temperatures given and not the validity of the proposed operating mode.

There is an even more advanced mode of operation which requires several design changes in the heat pump and the controls system. Figure 28 shows a heat pump using a water-to-water mode which can heat DHW using the field, heat DHW using the energy removed from the residence, cool using the field, and cool using the field in conjunction with the heat pump.

ENTHALPY EXCHANGER

Earlier in the discussion of infiltration control, an enthalpy exchanger was discussed as one means of significantly reducing thermal loads associated with infiltration without encountering problems with indoor air pollution.

An enthalpy exchanger is essentially a device much like a heat exchanger which is capable of the transfer of both energy and moisture. If cool dry inside air is exhausted through the enthalpy exchanger while hot-humid outside air is being pulled inside through the enthalpy exchanger the two air streams exchange both energy and moisture. Readily available exchangers are capable of reaching efficiencies of 70-80% or greater. This means the makeup air is within 70-80% of the conditions of the inside air. This gives both a sensible and latent ventilation load reduction of 70-80%. By combining the enthalpy exchanger with reduced infiltration rates one can reduce latent loads due to external ambient conditions by a factor of 12 to 20 compared to a typical conventional or typical passive structure. As one can see, passive structures can be designed for hot-humid climates which have latent loads very similar to the latent loads for structures in dry climates. This permits the passive cooling effort to be directed primarily toward sensible loads. This approach requires passively cooled structures designed for hot-humid climates to be very tight, i.e., have very low infiltration rates. Since the enthalpy exchanger works just as well during the heating season, the structure needs to again be tightly closed during the winter months.

Figure 29 shows a simple cross flow enthalpy exchanger operating during summer months. The temperatures and humidities are representative of what one might find in Atlanta. A sensible efficiency of 80% and latent efficiency of 70% was assumed.

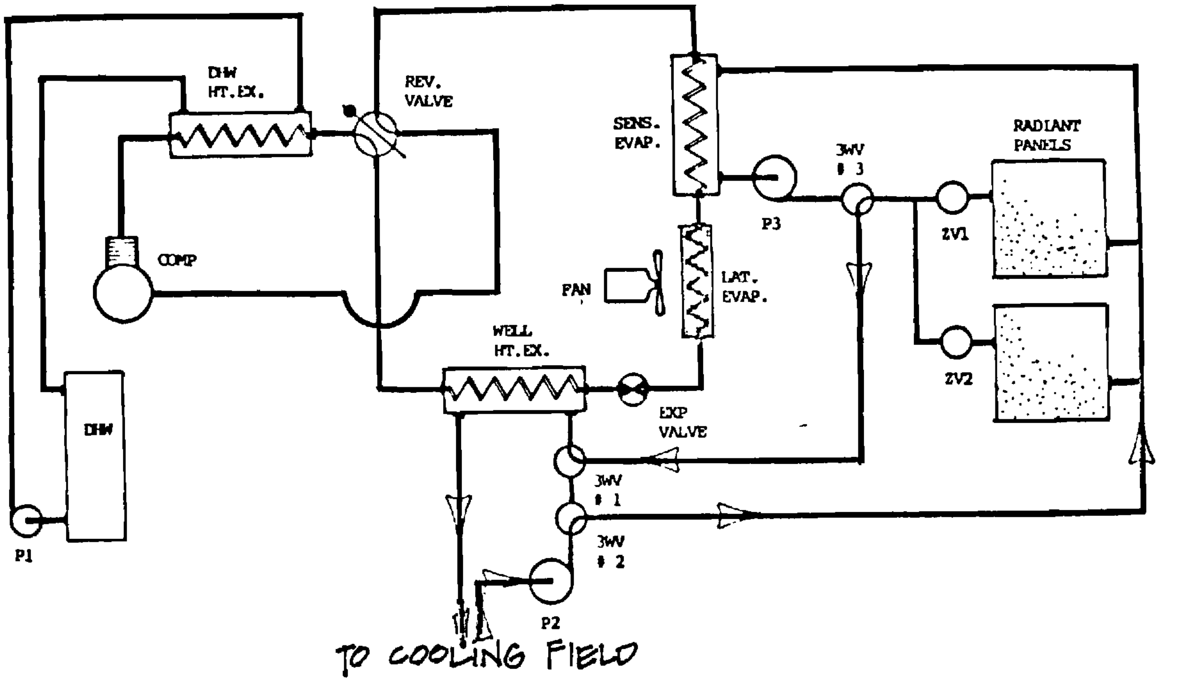



Figure 28. Multimode Water-to-Water Heat Pump

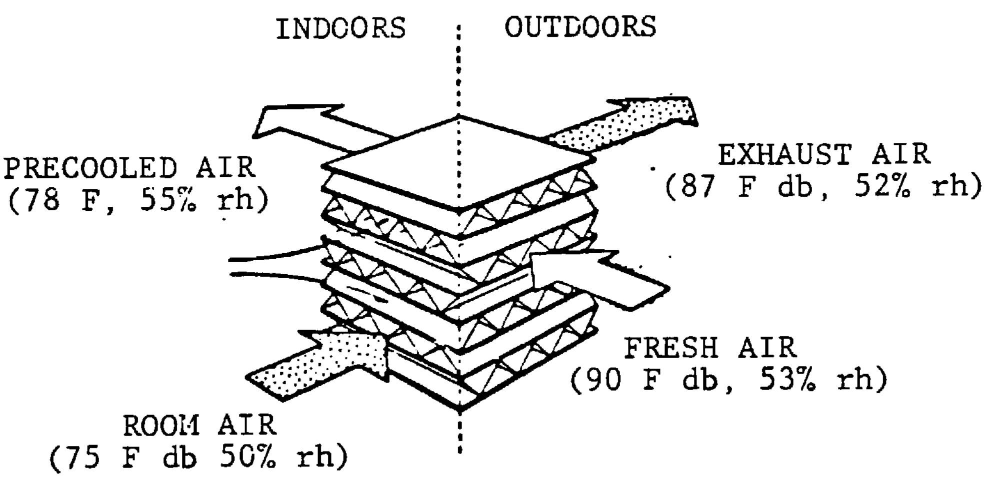



Figure 29. Enthalpy Exchanger Performance Figure

CONCLUSIONS

These tests show that the Detached Earth Tempering concept is capable of storing "coolth", i.e., the capacity to cool, from winter to summer relatively efficiently. When coupled to the building through building elements, such as concrete floors or walls, the concept provides cooling efficiencies greater than any other method.

The tests showed that overall system efficiency is highly dependent upon the optimization of all conponents. Use of a non optimized water circulation pump caused the systen COP in these tests to be only 6.4 to 10.9 for the four months cooled passively and 1.56 for the month when a water-to-water heat pump had to be used to boost the quality of the water, i.e., cool the water to below 70 F.

The importance of using a water-to-water heat pump with a high COP was also determined. The heat pump used the last month of the tests had a COP of approximately 2.0 which seriously decreased the system efficiency during the month of September.

Use of fans to boost the heat transfer rate of the air-to-water heat exchanger was shown to not be cost effective. More energy was used to increase the transfer rate than was stored as a result of the higher transfer rate.

Very preliminary calculations indicate that a pipe coil buried approximately 6" below grade, above the insulation, would be a much better method of transfering the energy from the detached earth block than is the metal fin air-to-water heat exchanger used in these tests. Use of a vertical well rather than a horizontal coil may permit one to provide water at satisfactory temperatures without having to insulate as one does with a horizontal field.

These tests have not looked at the economic feasibility of the Detached Earth Tempering concept. We have shown that the concept is technically feasible and very efficient. One would suspect that if the field must be insulated as in these tests the cost would be prohibitive. If the insulation can be eliminated, as was suggusted for a vertical array, and more cost effective ways of coupling the field to the building can be found, the concept may be highly competitive with the best of the other system with which it would compete.

# APPENDIX A

# GROCS/FIELD SIMULATION

# APPENDIX A

## GROCS

A FORTRAN computer model called GROCS (GROund Coupled System), was secured from the Brookhaven National Laboratory. This program had been adapted to work as a subroutine in TRNSYS (a TRaNsient SYstem Simulation program). GROCS was modified to work with the 10.1 version of TRNSYS which was already being used by Georgia Tech Personnel in several other programs. GROCS was further modified by Georgia Tech Personnel to increase the number of nodes possible so that a finer grain analysis could be made.

Instead of using a very fine grain mesh as is typically used in finite difference solutions to three dimensional energy flow, GROCS solves the heat flow finite difference equations over a system of "blocks" of earth. Each block is a volume of earth whose size and shape are determined from a hand drawn model. Figure A1 shows a model for a cooling coil field located 4 ft. beneath the surface.

The block-type model has the following advantages:

1. Useful problems can be solved with relatively short, economical, and simple programs.

2. Adequate accuracy can be obtained since naturally occurring ground inhomogeneities limit accuracy of any model that relies on bulk thermal properties to about 10%.

3. New earth-coupled models can be easily developed and evaluated.

GROCS uses three types of earth blocks. These are called adjacent blocks, free blocks and rigged blocks. The rigged blocks surround the free blocks which surround the adjacent blocks. The adjacent blocks are free blocks which are adjacent to the heat exchange surface. Fixed blocks have a fixed temperature which is determined by a subroutine called TINTERP. TINTERP reads measured ground temperature data from an input table and interpolates to determine the temperature of the rigged blocks for each month.

Initial free block temperatures are usually input as data. If these temperatures are input as 0 the subroutine TINTERP assigns initial temperatures as a function of depth and month as with the rigged blocks. While rigged block temperatures at subsequent time steps are determined by TINTERP, free block temperatures are determined by their thermal interaction with each other and with the rigged blocks, and by heat inputs to them from the field.

The major approximation which is made by the buried pipe model which is used to simulate the field is the substitution of a flowing plane sheet of fluid for the buried pipe field. This is showns in Figure A2. The method for correcting for the approximation was to calculate a correction factor for the area between the field and the adjacent blocks based on the pipe radius and spacing. The correction factor may be determined by equation A.1 below.

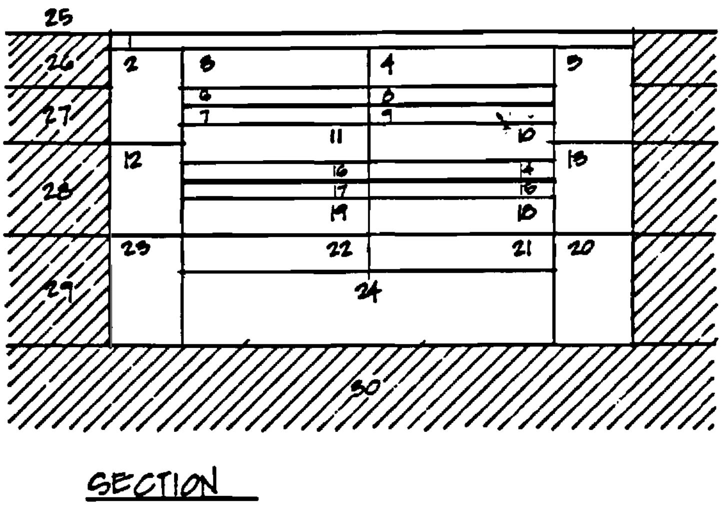



Figure A.1. Model Used For Computer Simulation of Field

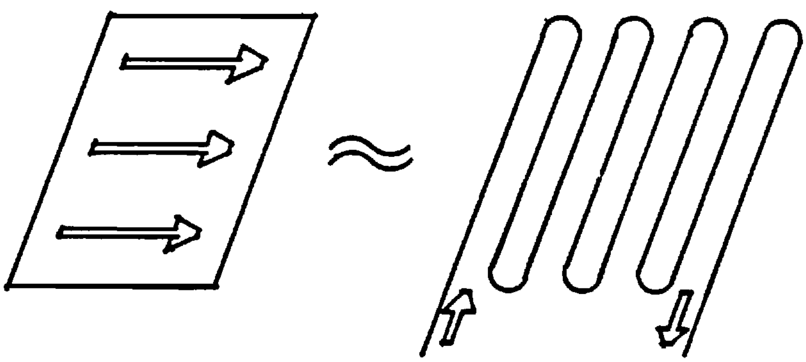


Figure A.2. Sheet Flow Approximation of Buried Field

$$\eta = \left( \frac{\pi h}{s} \right) * \left( \frac{1}{\ln \left( \frac{s}{\pi R} * \sinh \left( \frac{\pi h}{s} \right) \right)} \right) \qquad \text{(A.1)}$$

Where: $\eta$ = correction factor
h = the half-width of the adjacent blocks
s = tube spacing
R = the tube radius
sinh = hyperbolic sin

The accuracy of this approximation was checked by running a model on both GROCS and MITAS (Martin Marietta Interactive Thermal Analysis System) and comparing the results. MITAS is a large thermal network program capable of using a large number of nodes and requiring a time consuming model development and considerable computer time to run the model. It was determined that the results predicted by GROCS agreed with those predicted by MITAS to well within the 10% limits caused by uncertainties about soil properties and ground inhomogeneities. While GROCS was always run with fewer than 50 blocks, MITAS was run with over 1000 nodes.

Three basic models were simulated in these tests, a single plane model shown in Figure A3, a double level model shown in Figure A4, and a double level model beneath a house which is shown in Figure A5. Each of the basic models was run through many parametric simulations to determine the effect of different controllable variables. Details of the various models and the results obtained from the parametric studies will be discussed in a later section.

2.1.2. Variable Surface Temperature

When simulations of the double level field beneath the house were begun, it became desirable to have a variable outside temperature so that temperature swings within the house throughout the day and year could be observed. This was accomplished by adding a subroutine called VARST to TRNSYS. VARST calculates a sinusoidal daily and yearly surface temperature which can then be used to vary the temperature of the first rigged block.

The equations used to predict the ground temperature at any depth and any time of the year were modified by superposition of a daily temperature swing as predicted by equation A2.

$$Thr = Tave + \left(\frac{Tswg}{2} * \sin \left(360 * \frac{hr + 15}{24}\right)\right) \qquad \text{(A2)}$$

| | | | |
|---|---|---|---|
| Where: | Thr = | Temperature at time hr | ( F) |
| | Tave = | Average monthly temperature | ( F) |
| | Tswg = | Daily temperature swing | ( F) |
| | hr = | Hours after midnight | ( F) |

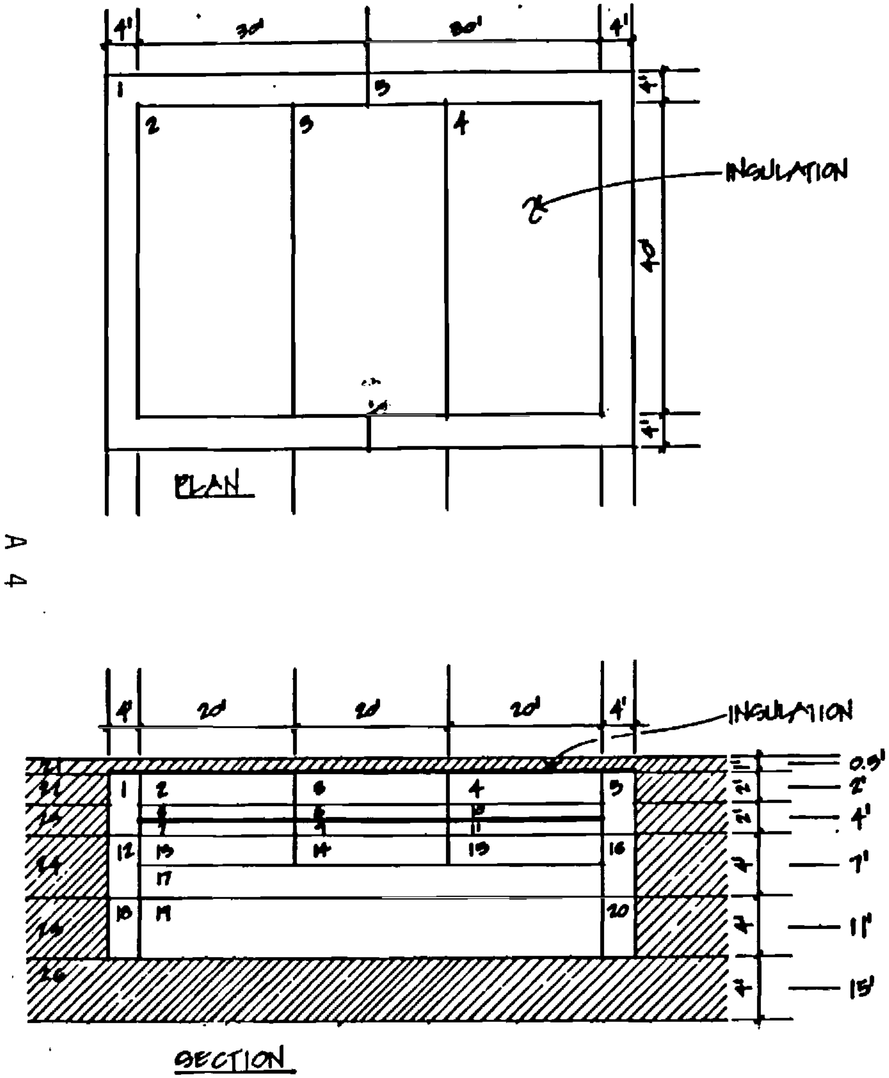



Figure A.3. Double Level Field Model

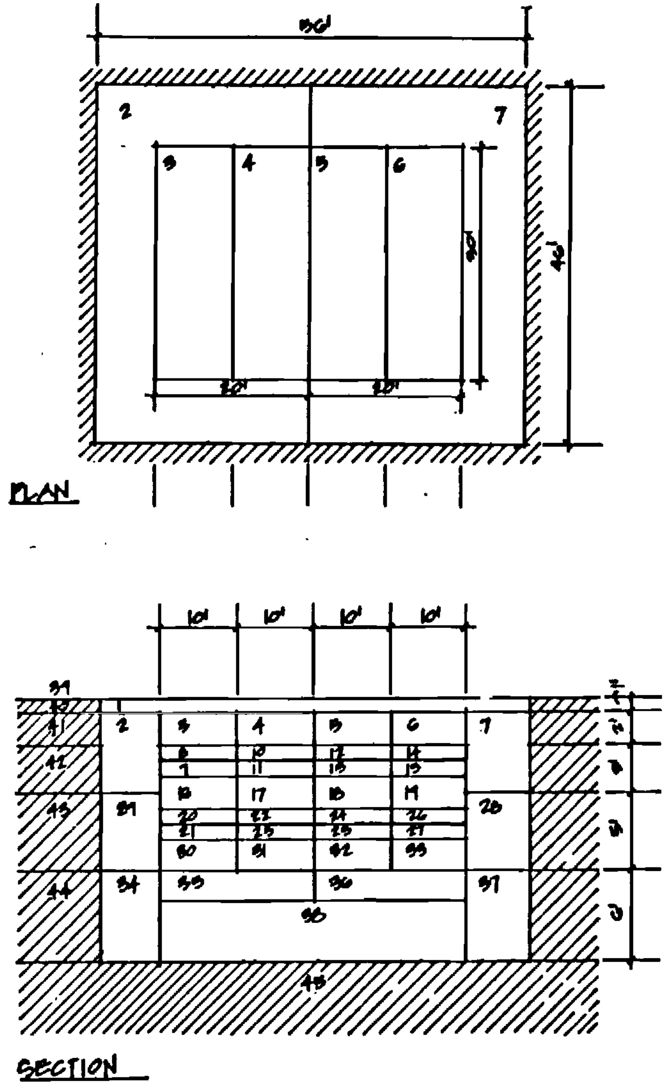



Figure A.4. Field under House Model

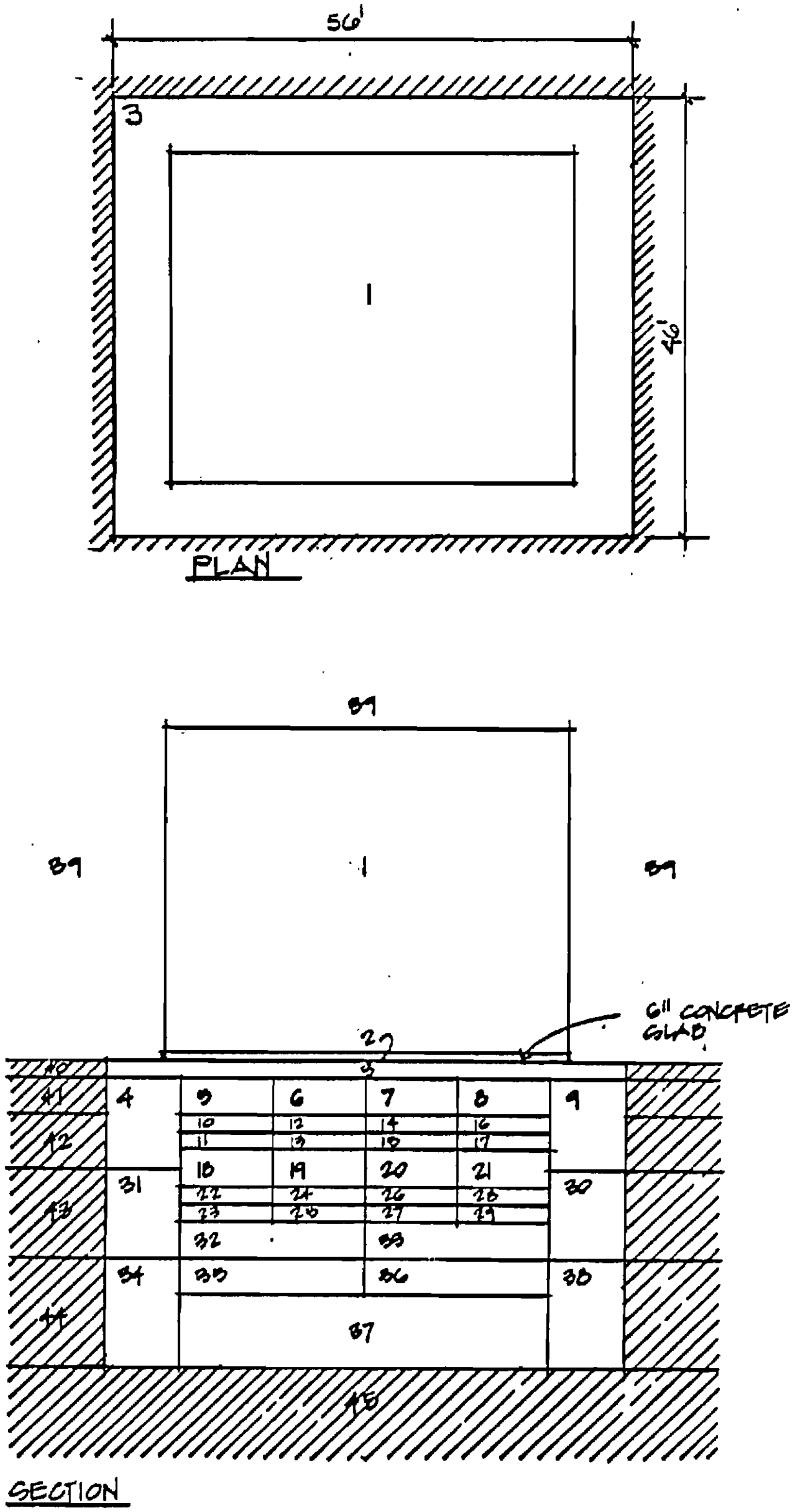



Figure A.5. Model of Field Under House

When this equation is superimposed on the ground temperature equation for a depth of zero (surface) one gets equation A3.

$$Tsur = Tm - (As * \cos (\frac{360}{365} * (Day - Day0))) + \frac{Tswg}{2} * \sin (360 * (\frac{hr + 15}{24}))$$

Where:

| | | | |
|---|---|---|---|
| Tsur | = | Temperature at time hr | ( F) |
| Tm | = | Average monthly temperature | ( F) |
| As | = | Daily temperature swing | ( F) |
| Day | = | Day of the year | |
| Dayo | = | Days after Jan 1st when minimum temperature occurs | |
| Tswg | = | Daily temperature swing | |
| hr | = | Hours after midnight | |

The variable surface temperature only became important and was only used when the model being simulated had a field beneath a house and one wished to observe the temperature swings within the house when no auxilliary cooling was used.

## FIELD SIMULATION

As briefly discussed above, three basic different fields were simulated in these analyses, a single level field at a depth of 4 ft., a double level field with one level at 4 ft. and one at 8 ft. and finally a double level field similar to that above but located under a house and coupled to the house through a slab floor. Parametric studies were conducted on each basic type to determine the optimum tube spacing, the optimum insulation thickness and the optimum energy extraction rate.

### Single Level Field

The single level field was located at a depth of 4 ft. and was limited to a plan area of 2400 sq. ft. 40' x 60'. Parametric studies were conducted to determine optimum tube spacing, optimum insulation thickness and optimum insulation placement. These simulations showed that horizontal placement of the insulation beyond the edge of the coil field was better than a vertical placement down along the edge of the field. The 4 ft. extension beyond the edge of the coil field was selected as the optimum distance because insulation cost was increasing much faster than the energy loss was decreasing.

Figure A1 shows the basic model used in the single level field simulations. Notice that the same basic model is used for all single level simulations. One only needs to vary the area between adjacent blocks to take into consideration any insulation which may lie between the blocks. The model was originally set up for an energy extraction rate of 6000 Btu/hr which remained constant until the field was no longer capable of supplying energy at that rate. The fluid flow rate through the field was adjusted to keep the energy extraction rate constant until the mass flow rate reached 4000 lbs/hr. This required the flow rate to be continually adjusted throughout the simulation. Flow rate would be low during the initial hours when the field temperature was low. Flow rate would then increase until it reached a maximum of 4000 lbs/hr, at which point the field could no longer supply 6000 Btu/hr and the cooling capacity would begin to drop.

Figure A6 shows the effect of insulation on the time the field is capable of supplying the 6000 Btu/hr. Notice the significant improvement when going from no insulation to R10 insulation and the still further improvement with further increases in insulation.

These simulations indicated that while the single level field would be capable of supplying a significant percentage of the total cooling load of a well insulated house passively, the quantity and thickness of insulation required was significant because the plan area was large and the greatest losses were through the insulation to the surface. This suggested that a double level field of less plan area might offer a significant improvement.

Double Level Field

The single level field simulations suggested that a double level field would not only perform better but would also cost less to construct. Figure A7 shows the basic model used for the double level field. Since the field depth was twice that of the single level field, the plan area of the double level field was reduced to 1200 sq. ft. 30' x 40'. The insulation was extended 8 ft. beyond the edge of the pipe field, i.e., equal to the greatest depth.

The GROCS subroutine was modified to increase the number of earth blocks possible, for simulation of the double level field so that the energy flow paths could be more closely followed. Parametric runs similar to those conducted on the single level field were also conducted on the double level field. Since the double level field used 1.25 in. nominal inside diameter pipe, the pipes were placed on 3 ft. centers rather than 4 ft. as had been used on the single level field. This permitted 500 ft. of pipe to be positioned in each of the two levels.

Maximum energy extraction rates and maximum fluid mass flow rates were kept identical to those used in the single level field simulations. Figure A4 shows that the double level field does indeed perform better than the single level field, with the uninsulated performance of the double level field being better than the R10 insulated performance of the single level field. R10 insulated performance of the double level field is again much better than the uninsulated performance. While some improvement is evident with perfect insulation between the field and the surface, the improvement is not nearly as great as was experienced with the single level field. Notice that there is little difference in performance of the single and double level fields when both have perfect insulation between the field and the surface.

Double Level Field Beneath A House

The plan area of the double level field had been decreased to the point where one could begin to consider putting the field beneath the house rather than in an open field. This serves several important purposes. First, it decreases the impact of high solar imput to the field surface. Second, energy gain to the field through the top surface serves to cool the residence rather than being lost to the ambient air.

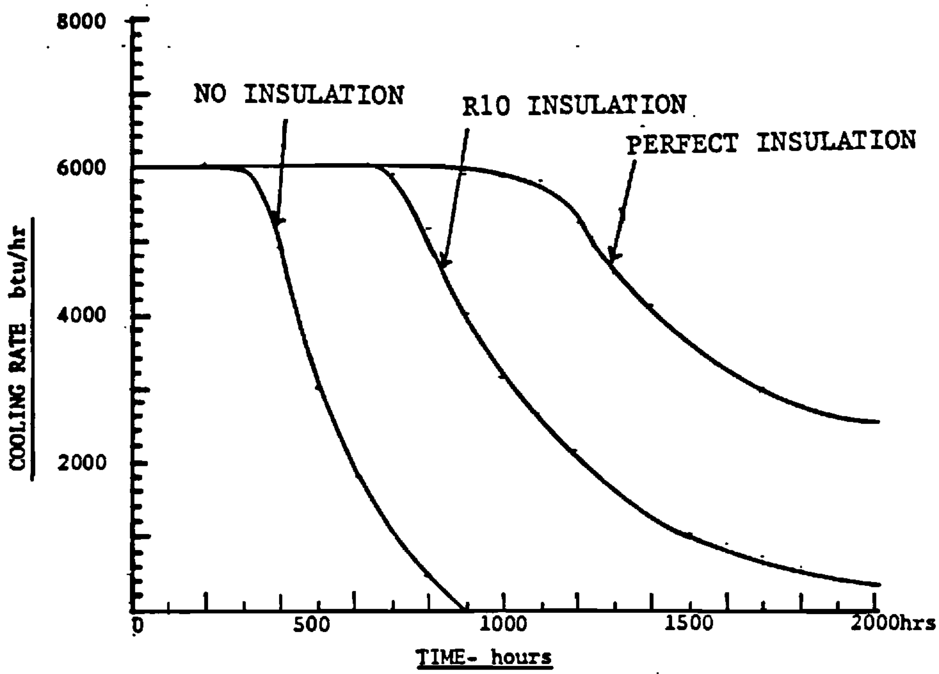



Figure A.6. Effect of Insulation on Single Level Field

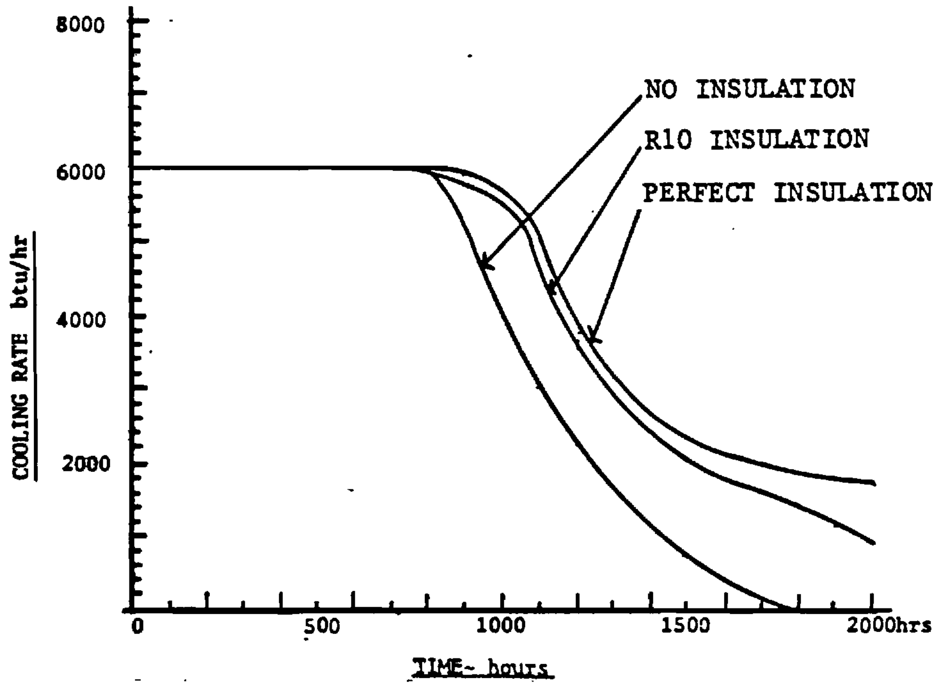



Figure A.7. Effect of Insulation on Double Level Field

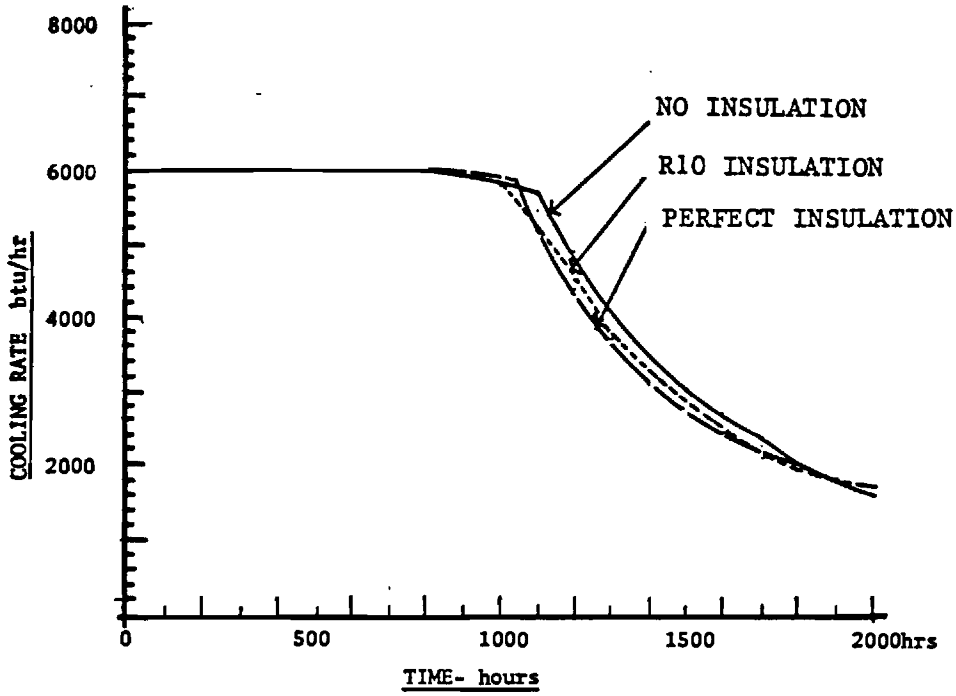



Figure A.8. Effect of Insulation on Field Under House 6000 Btu/hr.

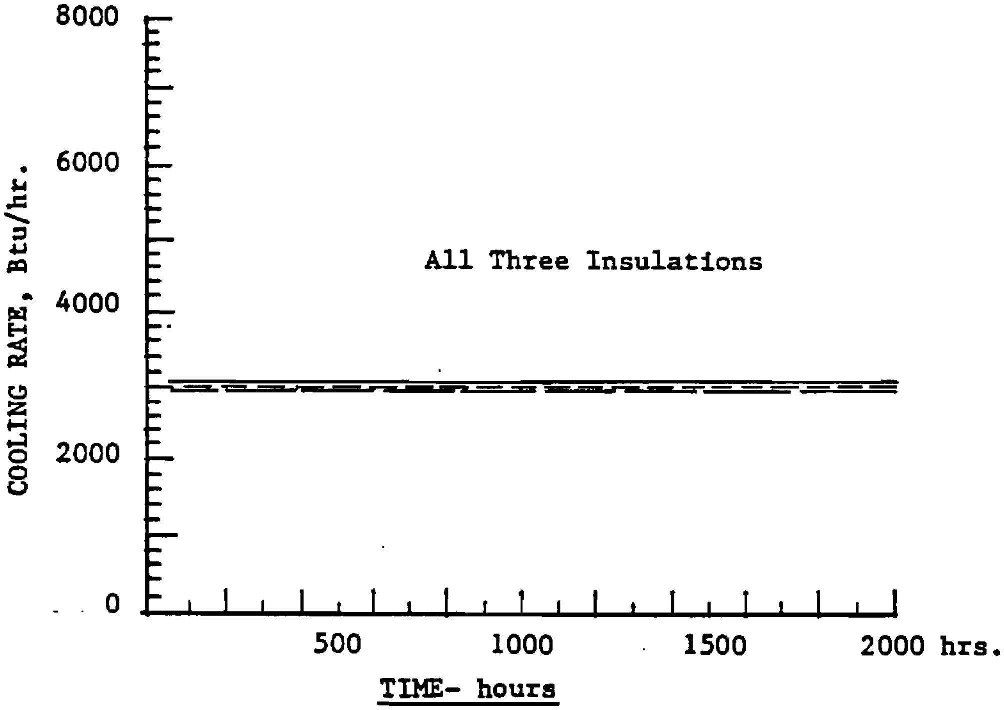



Figure A.9. Effect of Insulation on Field Under House- 3000 Btu/hr

Figure A5 shows the basic model used for the field beneath the house. Notice that it is identical to the double level field discussed above, with the addition of a concrete floor and house above the field. It was felt that a passive approach such as this would be most effective when used with a very well insulated house. A 1600 sq.ft. house with a UA of 350 Btu/hr F was chosen for the simulations.

Simulations were run for both 6000 Btu/hr and 3000 Btu/hr energy extraction rates. Figures A8 and A9 show the results from both of these cases. One could say that the lower extraction rate would obviously continue to work longer than the higher rate and that it would also have worked longer for both the single and double level fields discussed above, and one would have been correct. What prompted the simulations using the lower extraction rate was a study of the floor and ambient air temperatures within the house without using the cooling capacity being extracted through the tubing. It was found that the house could be maintained at a comfortable temperature without using any of the energy being extracted through the tubes, i.e., the field coupled to the house through the concrete floor provided sufficient cooling to meet the cooling load without any auxilliary cooling. It appears from these initial simulations that the system must be carefully designed to prevent overcooling during the early part of the summer.

# APPENDIX B

# GROUND TEMPERATURES

## APPENDIX B

## GROUND TEMPERATURES

Although the ground temperature prediction equations are considered to be quite accurate, it was decided to sink two forty ft. wells to permit ground temperatures to be monitored. Figure B1 shows the well locations relative to the field location. The well location was chosen so that one well would be located vertically through the field and one would be located about 50 ft. west of the field hole and sufficiently far from the field to not be affected by the energy transferred to the ground by the field.

Figure B2 is a cross section through one of the wells showing thermocouple location. The thermocouples are positioned in a sand filled PVC tube with each thermocouple bead projecting through a small hole in the tube and being bonded to the exterior of the tube. Since the PVC has a conductivity of only 1/10 that of soil, the tube should not affect the thermocouple measurements. Once the thermocouple tube was located vertically in the hole, the hole around the tube was backfilled with a 50/50 mixture of bentonite and cement. This mixture was chosen because it has a thermal conductivity not significantly different from that of the soil, it flows readily, and should not subsequently develop cracks which might affect soil temperatures. Figure B3 shows a detail of the PVC tube at one of the thermocouple locations.

Surprisingly, both wells hit water at 20-23 feet. This was surprising because all the soils experts in this area said that one should not hit water in the Atlanta area at depths less than 250 feet. The particular site chosen for the field is an old stream bed with a mixture of silt and clay as the predominant soil type. Apparently, considerable water remains in the soil despite the storm sewer shown in Figure B1.

While it would have been desirable to have a continuous measurement of soil moisture in the vertical wells as well as throughout the field, lack of suitable soil moisture probes precluded the installation of moisture measuring equipment. It had been anticipated that moisture measuring probes developed by the U.S. Forest Products Laboratory at Athens, Georgia, would be satisfactory for the soil moisture measurements. Mr. J. E. Duff of the Forest Products Laboratory advised that these probes are not satisfactory for soil moisture measurements. After talking with Mr. Duff, Dr. Tom Bligh of MIT, Dr. Phil Metz of Brookhaven National Laboratory, Dr. Jim Hartley of Georgia Tech and with Georgia Power personnel, it was concluded that no satisfactory remote soil moisture measurement device existed within our operation and budget parameters.

Soil samples were taken every five feet during the drilling operation. These samples were weighed, dried and reweighed. This permitted us to make an initial soil moisture determination and with the basic soil type and moisture content estimates of soil conductivity, diffusivity, and heat capacity were made. Table BI gives the soil weight and thermal properties as determined by these tests.

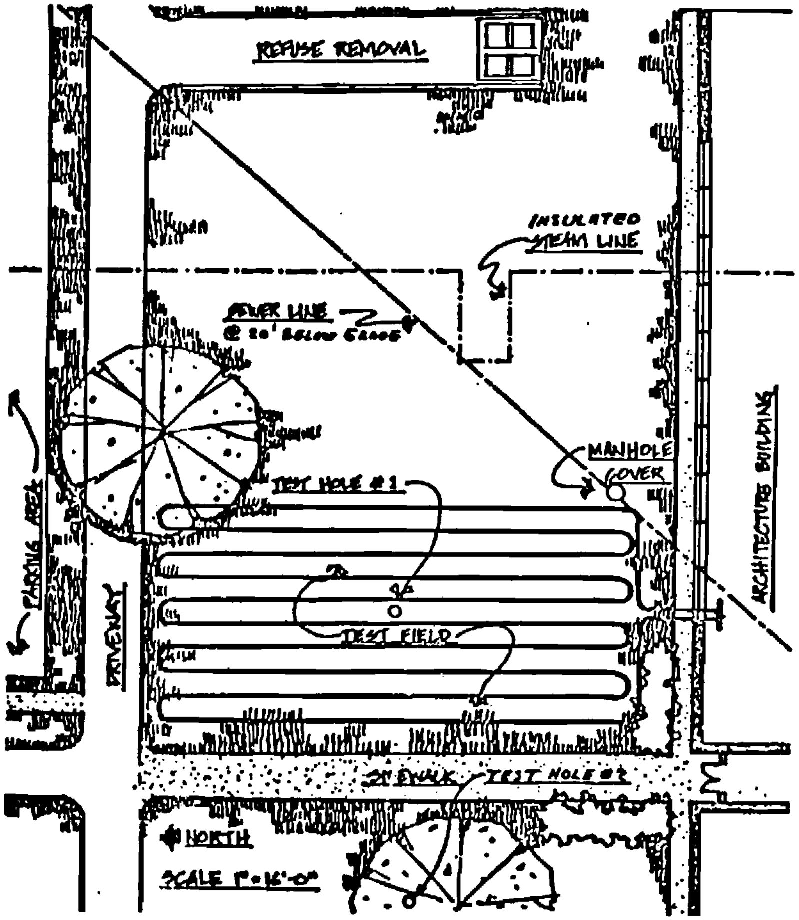



Figure B.1. Forty Foot Well Layout

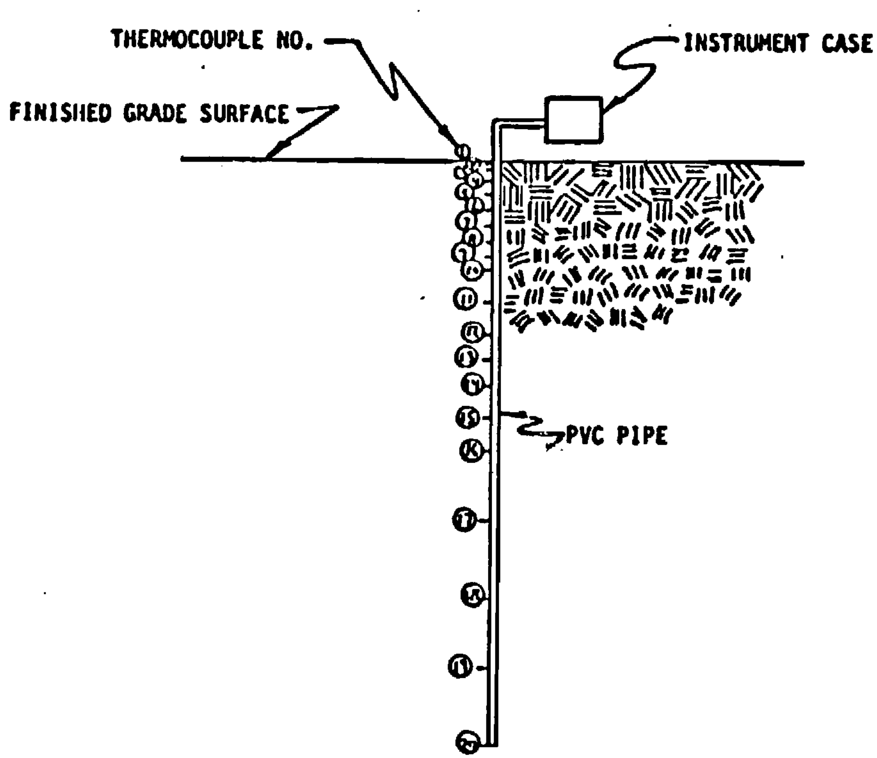



Figure B.2. Cross Section Through Well

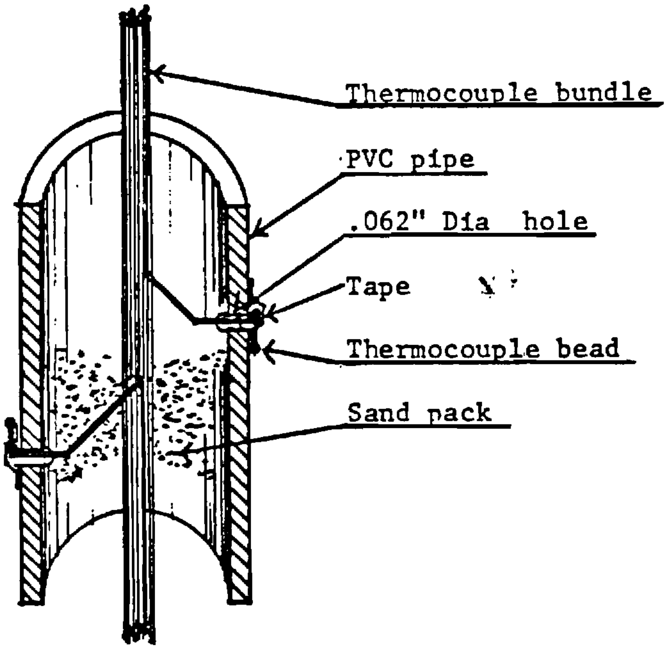



Figure B.3. Detail of Thermocouple Well

TABLE BI

| SAMPLE NUMBER | DEPTH Ft | DRY DENSITY Lbs/Ft$^3$ | MOISTURE CONTENT % Dry Wt. | THERMAL CONDUCTIVITY BTU Ft/Ft$^2$hr. °F | HEAT CAPACITANCE BTU/Ft.$^3$ °F | THERMAL DIFFUSIVITY Ft$^2$/hr. |
|---|---|---|---|---|---|---|
| B.1.1 | 3.5 -5.0 | 83.1 | 12.1 | .556 | 24.5 | .023 |
| B.1.2 | 8.5-10.0 | 61.4 | 27.1 | .609 | 27.3 | .022 |
| B.1.3 | 13.5-15.0 | 80.8 | 22.1 | .864 | 31.9 | .027 |
| B.1.4 | 18.5-20.0 | 86.1 | 25.2 | 1.052 | 36.6 | .029 |
| B.1.5 | 23.5-25.0 | 81.7 | 35.0 | 1.052 | 42.8 | .025 |
| B.1.6 | 28.5-30.0 | 79.2 | 35.0 | 1.015 | 41.5 | .025 |
| B.1.7 | 33.5-35.0 | 77.3 | 35.0 | .970 | 40.5 | .024 |
| B.1.8 | 38.5-40.0 | 81.8 | 35.0 | 1.054 | 42.8 | .025 |
| B.2.1 | 3.5 -5.0 | 67.4 | 17.9 | .590 | 23.8 | .025 |
| B.2.2 | 8.5-10.0 | 69.1 | 13.7 | .476 | 21.5 | .022 |
| B.2.3 | 13.5-15.0 | 71.1 | 23.6 | .727 | 29.1 | .025 |
| B.2.4 | 18.5-20.0 | 97.3 | 16.6 | 1.043 | 33.0 | .032 |
| B.2.5 | 23.5-25.0 | 84.2 | 35.0 | 1.167 | 44.1 | .026 |
| B.2.6 | 28.5-30.0 | 78.0 | 35.0 | .969 | 40.8 | .024 |
| B.2.7 | 33.5-35.0 | 76.5 | 35.0 | .937 | 40.0 | .023 |
| B.2.8 | 38.5-40.0 | 89.6 | 35.0 | 1.281 | 46.9 | .027 |
| Old Snow | | | | .16 | 14 | .01 |
| Dry Sand | | | | .1 | 19 | .005 |
| Wet Sand | | | | 1.0 | 25 | .04 |

Soil temperature measurements taken during the first three months were very close to those predicted by the equations, although temperatures measured in hole 2 were several degrees lower than predicted. Hole 2 is located adjacent to a large elm tree and is located on the north side of this tree. It appears that the tree is effective in lowering adjacent soil temperatures. It appears this effect is a combination of reduced solar input and evaporative cooling adjacent to the tree. Temperature measurements at Hole #1 during the summer months began to show a significant deviation from those predicted. The equations used to predict the soil temperatures assumes a sod ground cover. Hole #1 was located in an open field with little or no ground cover. Surface temperatures as high as 135 F were measured when the ambient temperature was less than 100 F. Surface temperatures at Hole 2 were consistently below the ambient temperature during the summer months. Temperatures in both holes at depths below the water level were identical and were about the 63 F predicted by the equations.

Figure B4 shows the temperature distribution from the surface to a depth of forty feet for both the test hole (that located in the cooling field) and the reference hole located about 56 ft. to the west. Notice the significantly lower temperatures in the reference hole for both dates than for the test hole. This difference results primarily from the reference hole being located in the shade of a tree while the test hole was in an open field with little ground cover. This illustrates the importance of ground cover for ground used for passive cooling purposes. The lower temperatures at the surface and one foot depth for the test hole in February results from the insulation at the one foot depth decreasing energy flow from the lower depths.

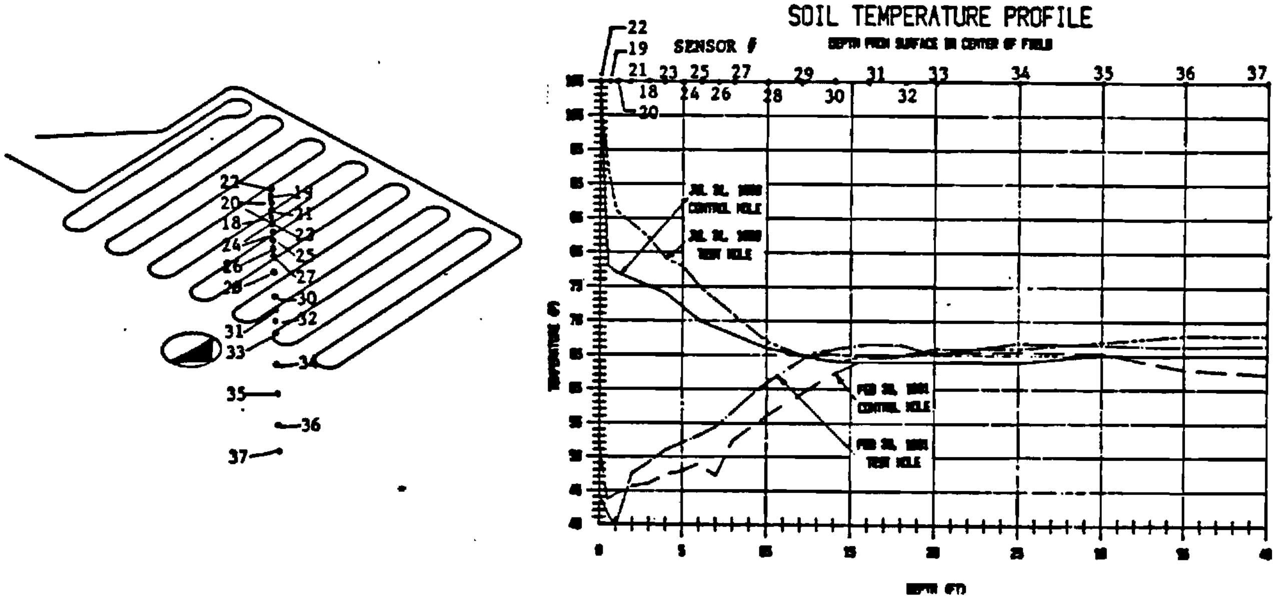



Figure B.4. Temperatures in Two Wells vs Time